

Observational Signatures of Magnetic Reconnection in the Extended Corona

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Supra-Arcade Downflows (SADs) Observations



Sadpoles, not tadpoles

Fig 1

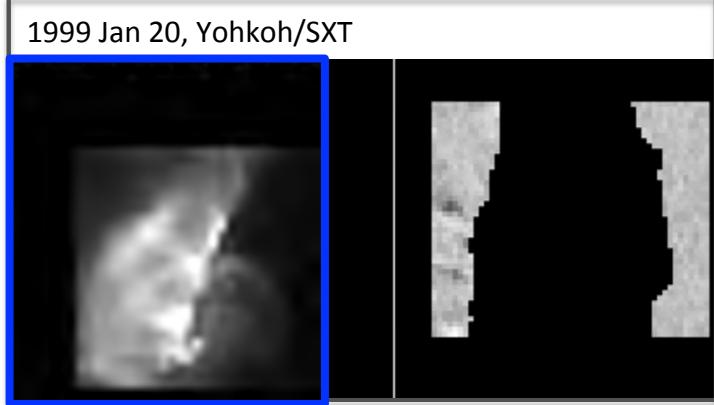
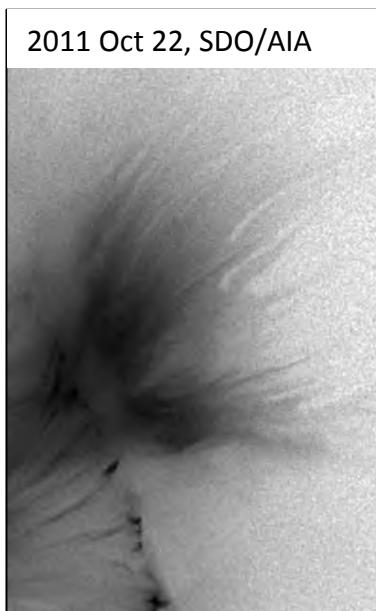


Fig 4



- Teardrop-shaped **voids** observed to travel sunward through the bright, hot fan extending outward along the spine of developing post-flare arcades.
- Observed with high-temperature instrumentation (EUV, X-ray) & white-light coronagraph (density)
- **LONG DURATION EVENTS**

Fig 2

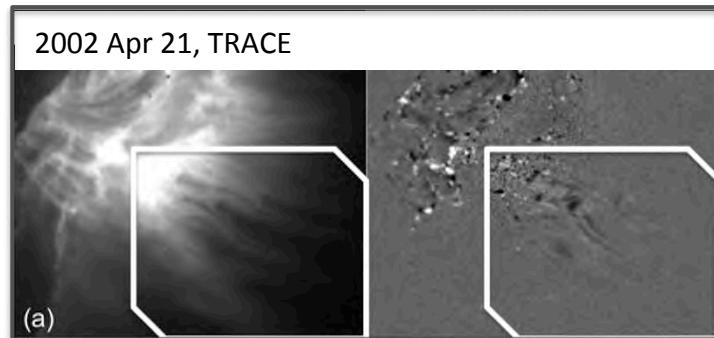


Fig 5

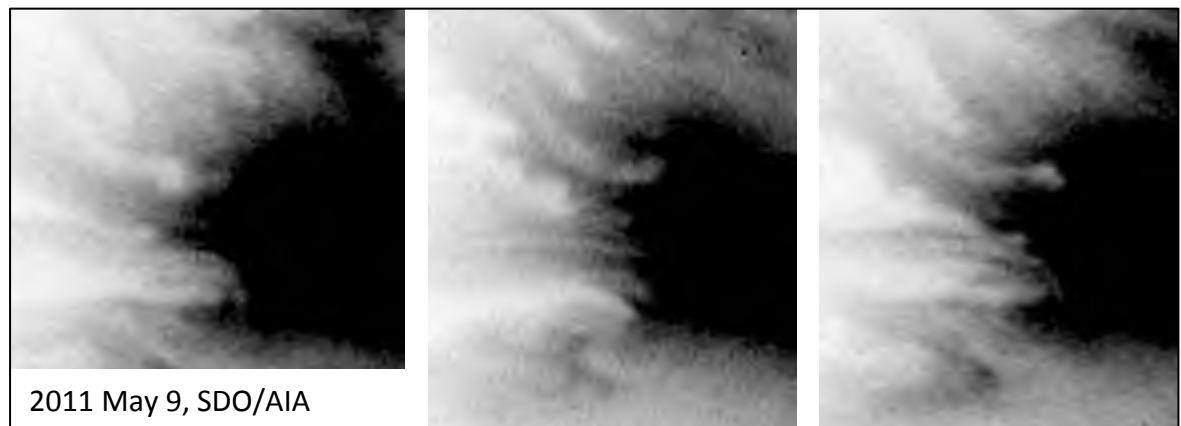
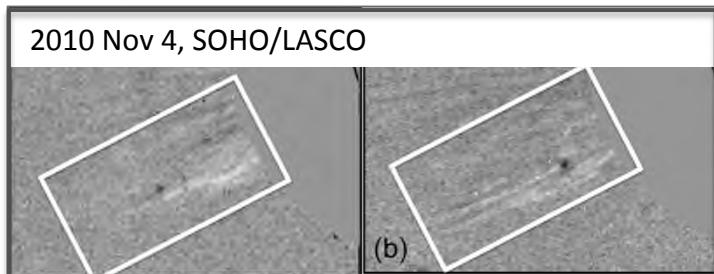
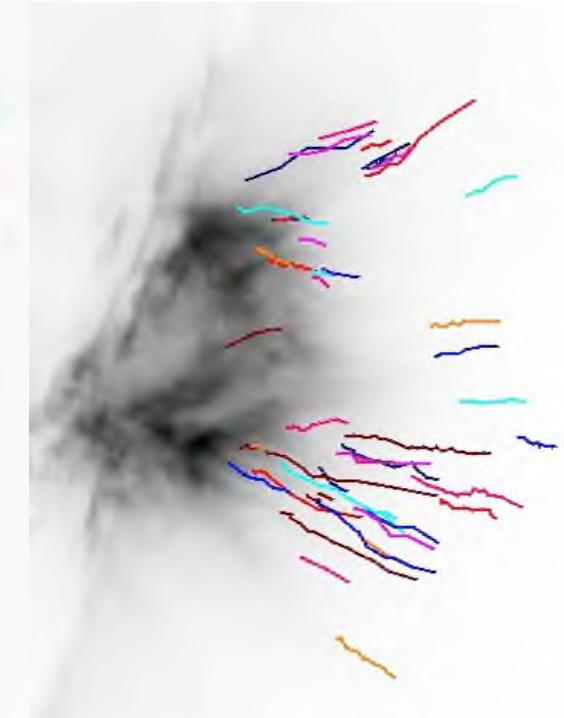
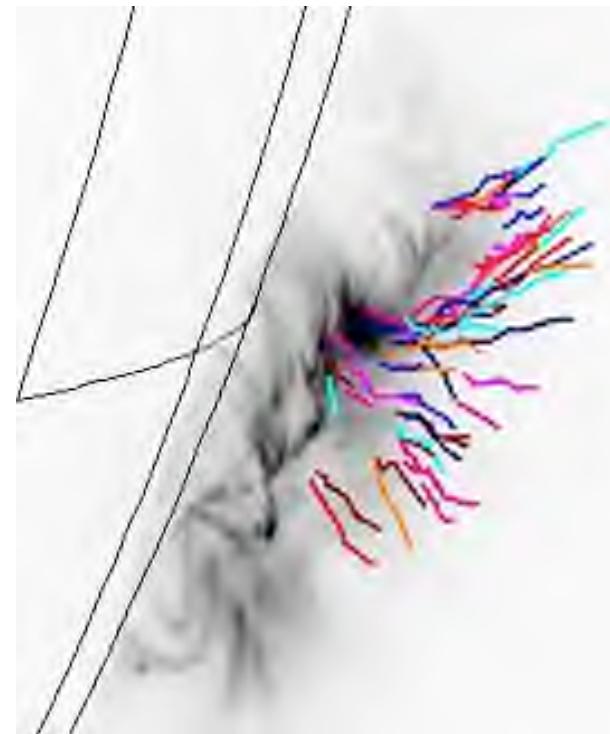
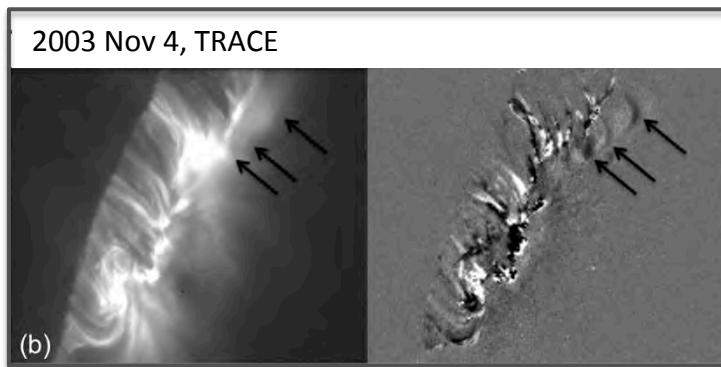


Fig 3



Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1



Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1

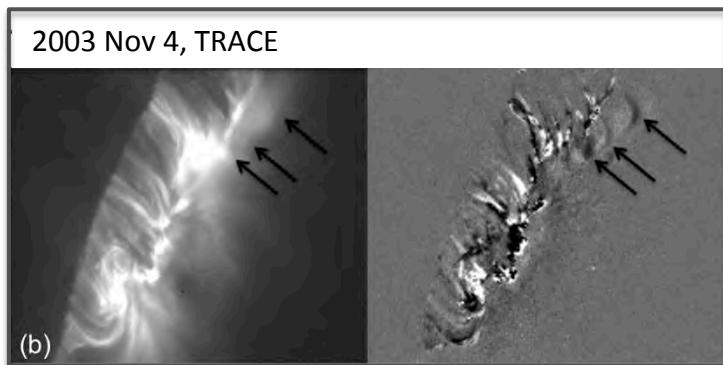
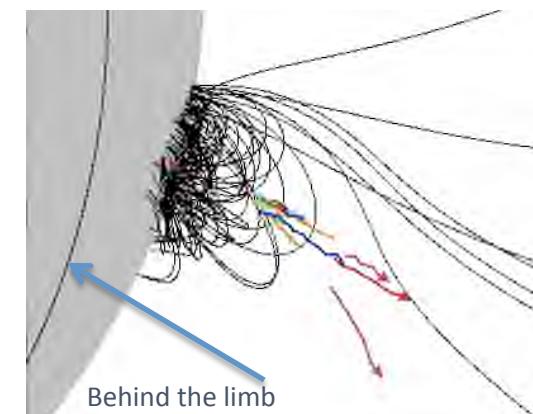
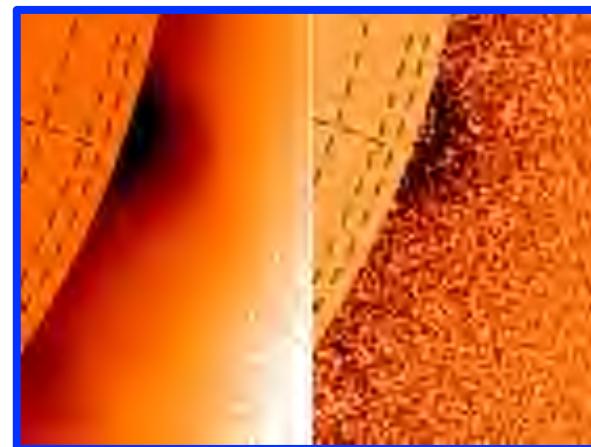
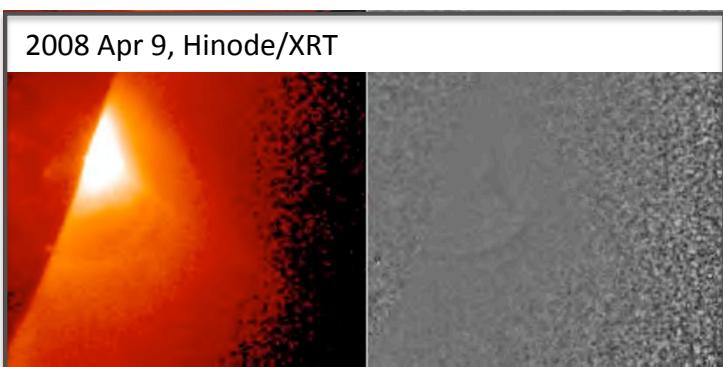


Fig 2



Supra-Arcade Downflowing Loops (SADLs) Observations

Fig 1

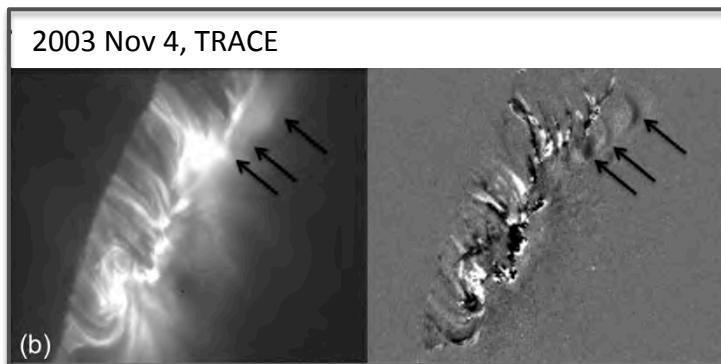
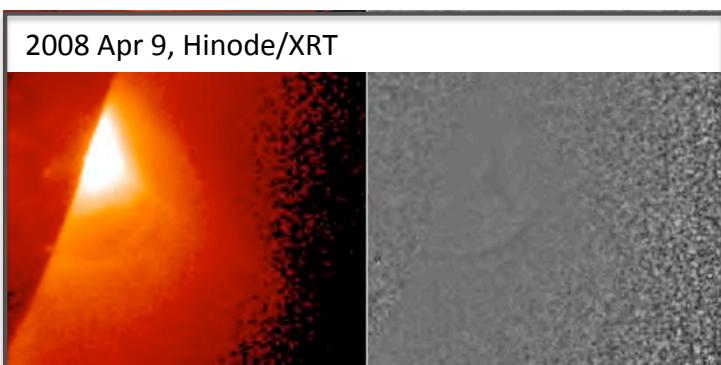


Fig 2



2010 Nov 3, SDO/AIA

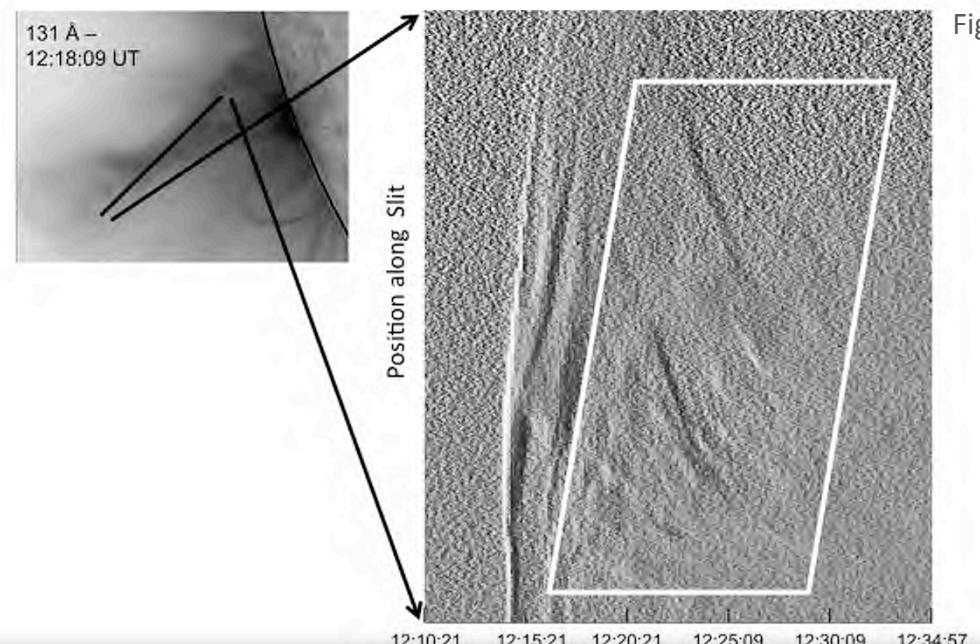


Fig 3

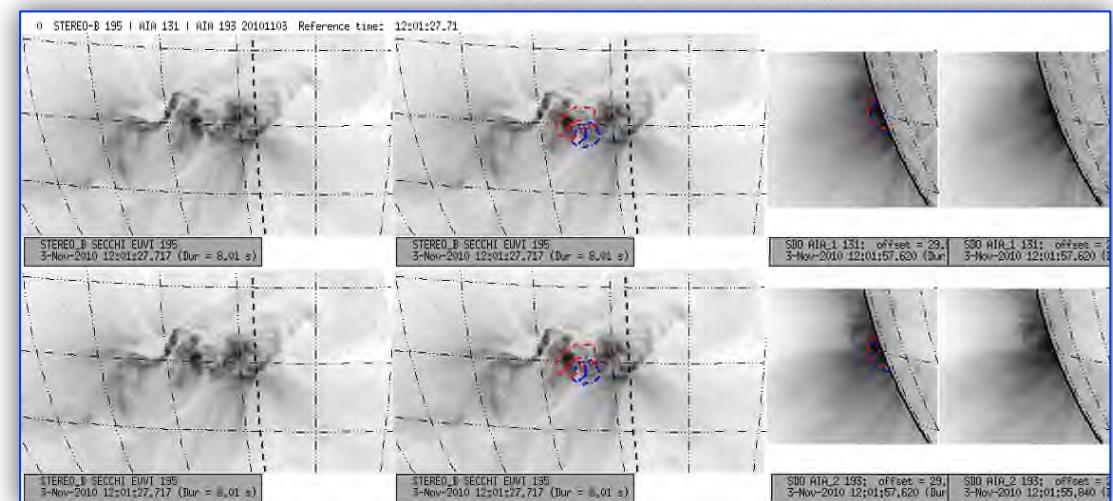


Fig 1: Savage & McKenzie 2011

Fig 2: Savage et al. 2010

Fig 3: Savage et al. 2012

Different from Plasmoid Observations

- Coherent 'bubble' of **emitting** plasma held together by magnetic fields.
- Observed with broadband-temperature instrumentation (EUV, X-ray, Hard X-ray) & white-light coronagraph (density)

➤ Magnetic Islands

Fig 1

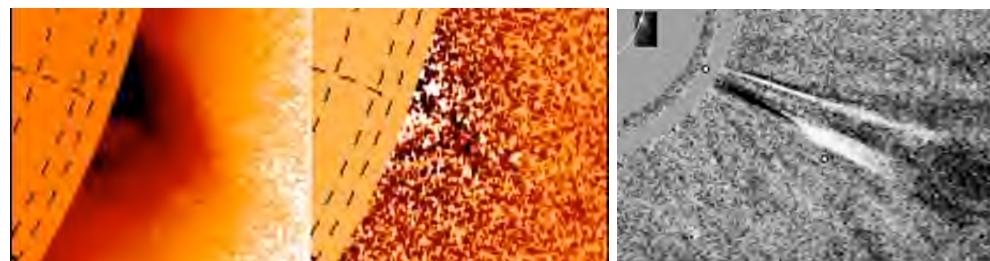


Fig 2

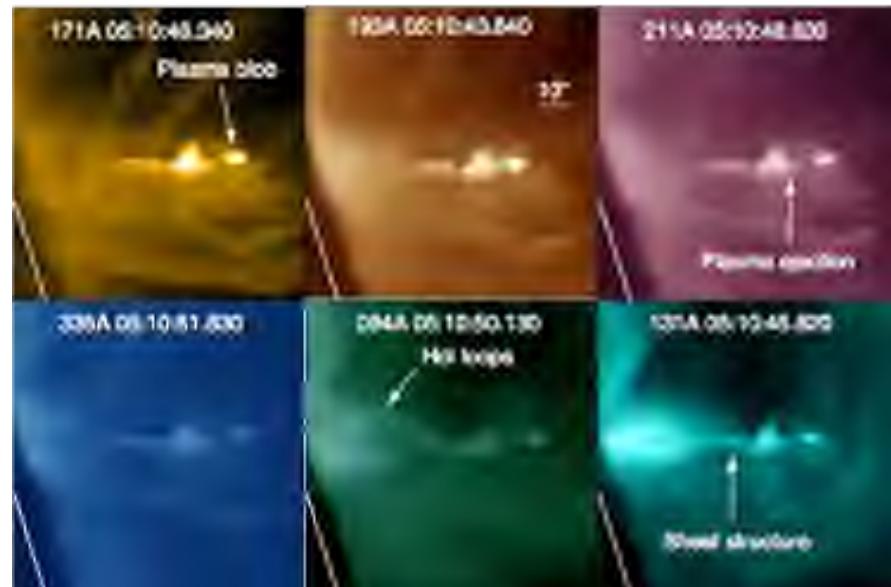
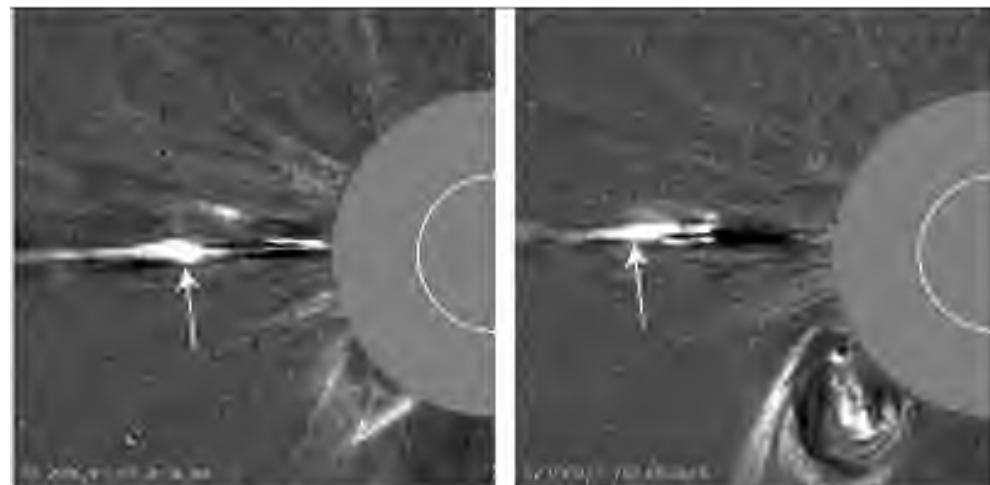


Fig 3

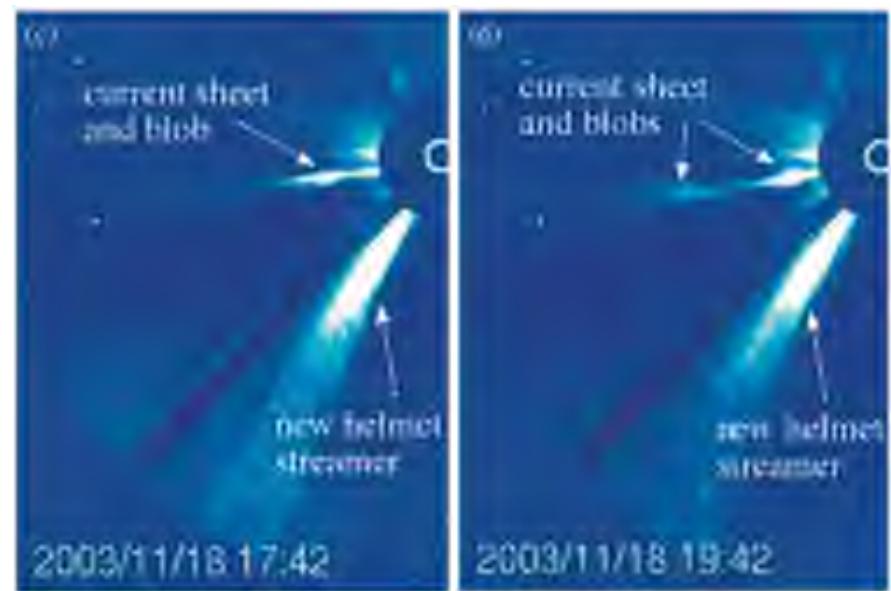


Fig 4

Fig 1: Savage et al. 2010

Fig 2: Ko et al. 2003

Fig 3: Takasao et al. 2012

Fig 4: Lin et al. 2004

Different from Plasmoid Observations

Fig 1

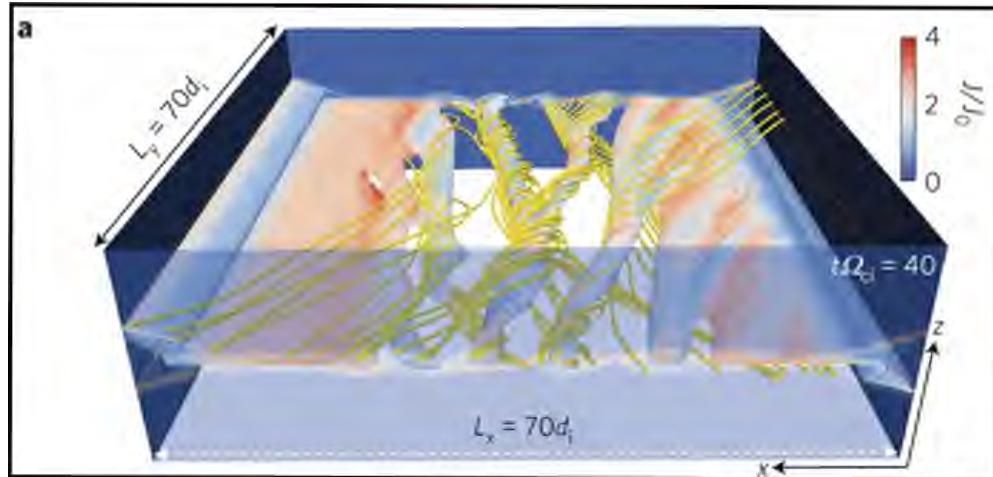


Fig 3

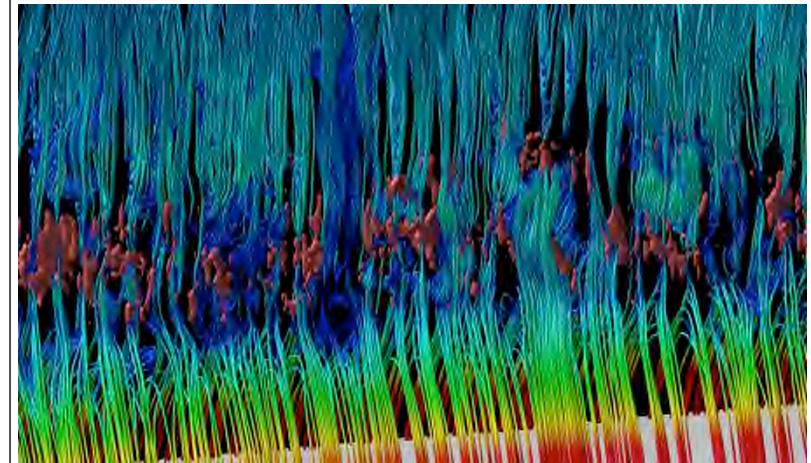
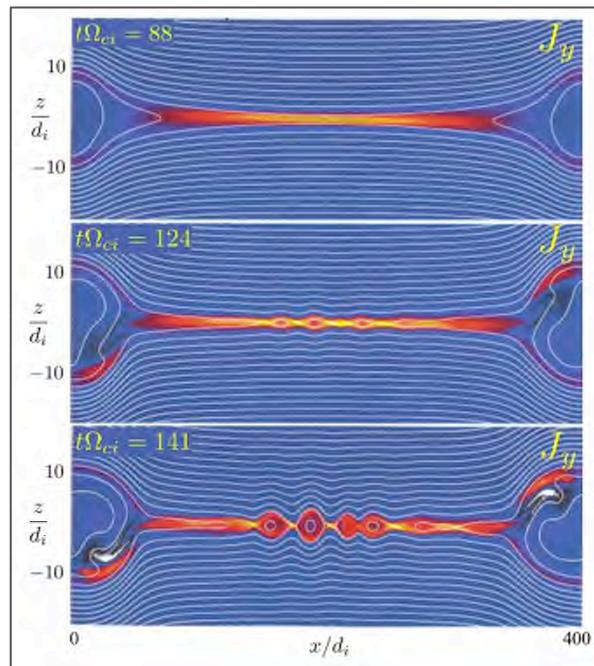


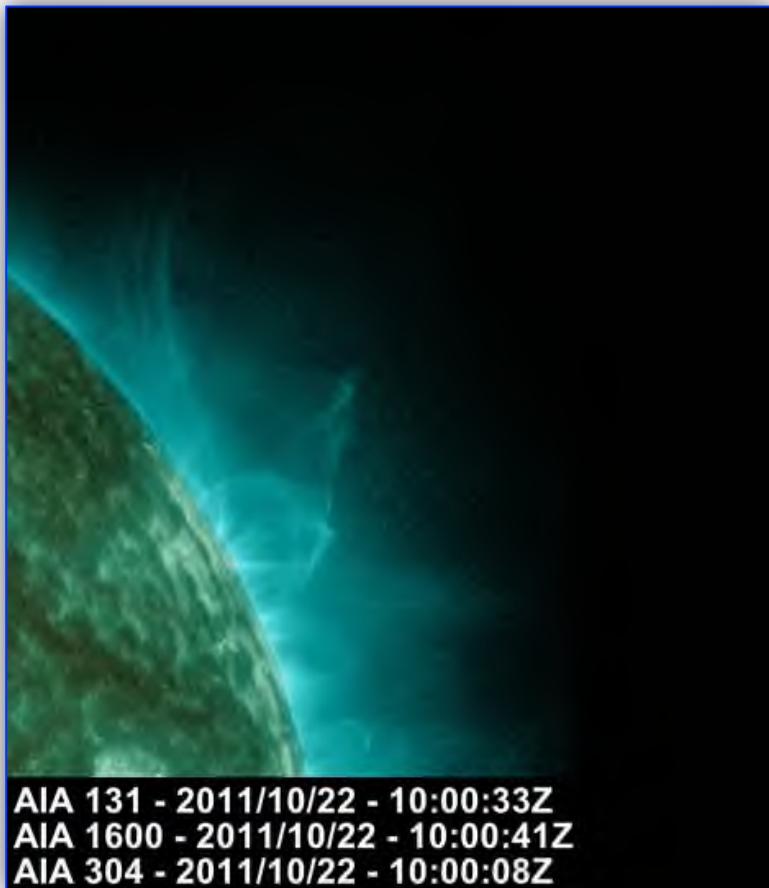
Fig 2



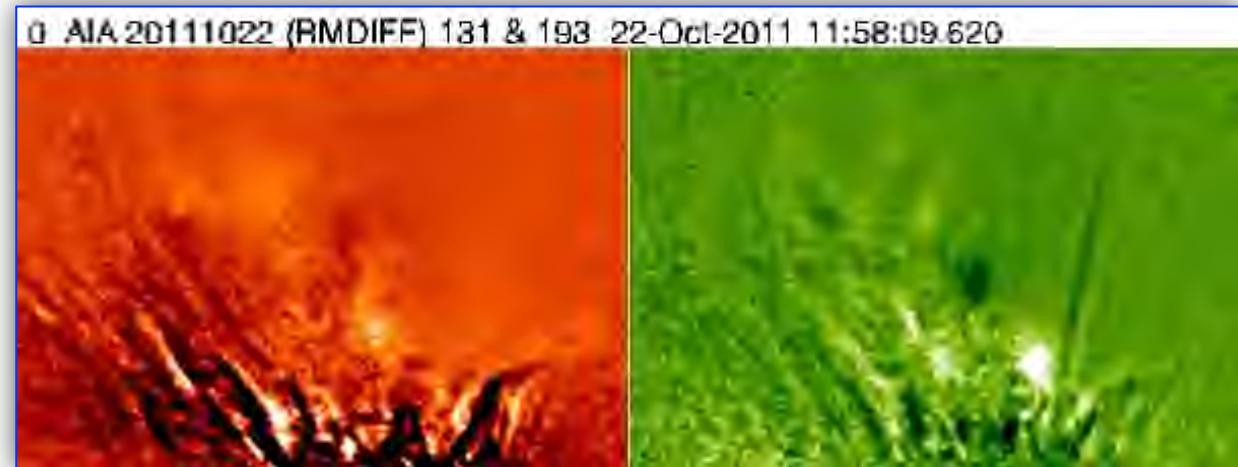
- Thin flux tubes created during the reconnection process across the current sheet.
- Plasmoids a 3-D product of reconnection concurrent to single loop creation.



SADs + SADLs



AIA 131 - 2011/10/22 - 10:00:33Z
AIA 1600 - 2011/10/22 - 10:00:41Z
AIA 304 - 2011/10/22 - 10:00:08Z

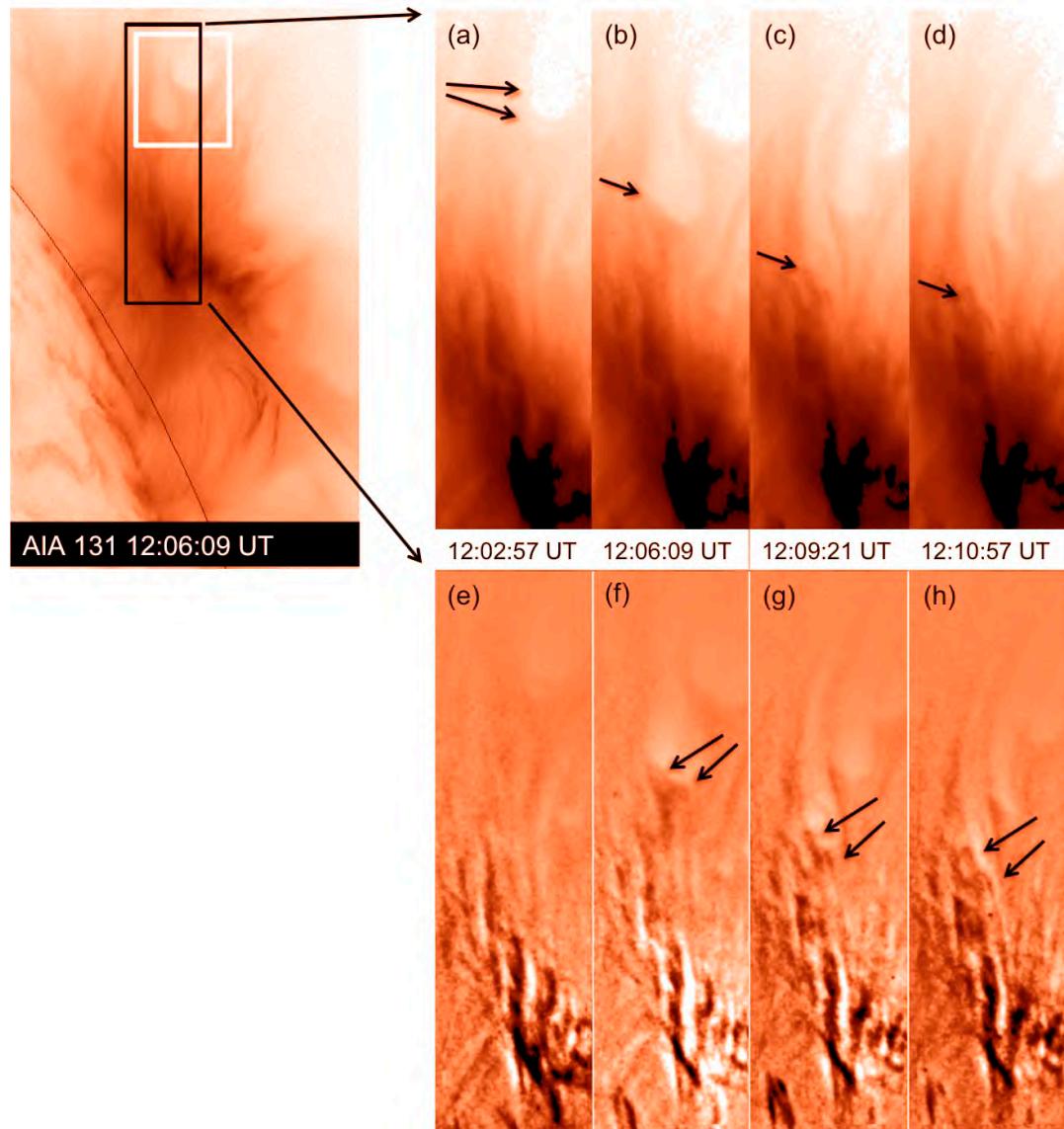


- Hot AIA channels. (2-10 MK)
- Differenced
- Reverse-scaled



SADs + SADLs

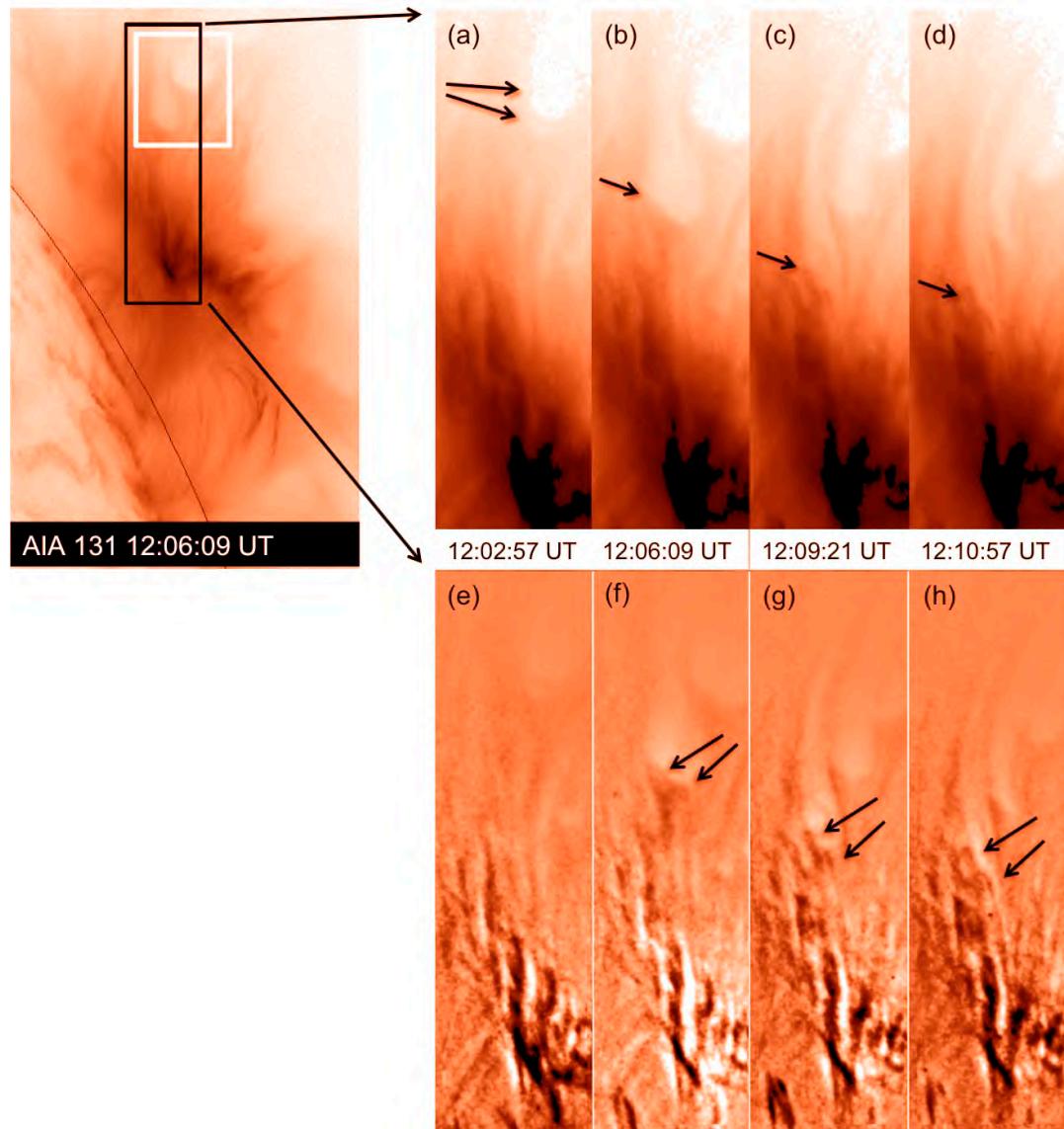
Fig 1



- SADs appear to be voids created by loops (SADLs) shrinking through the fan plasma.

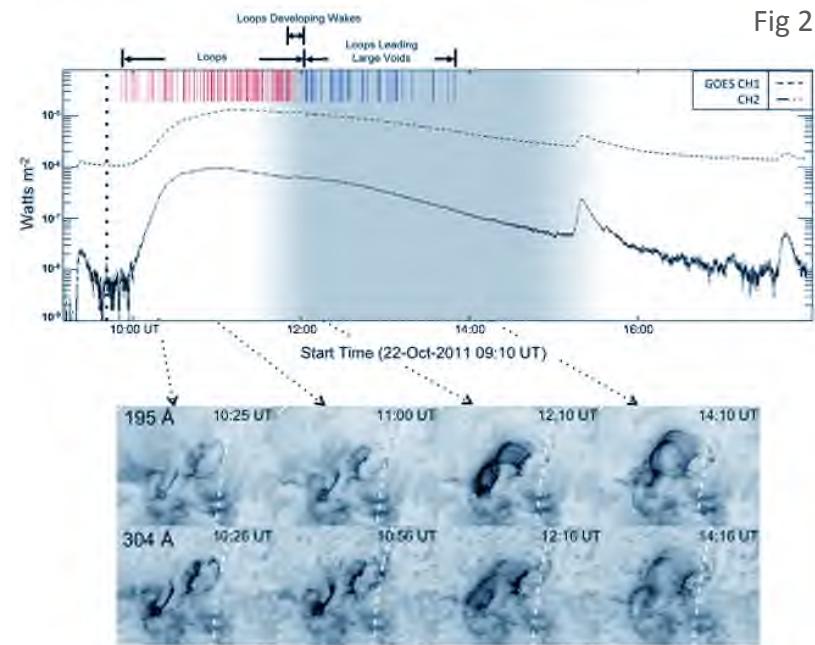
SADs + SADLs

Fig 1

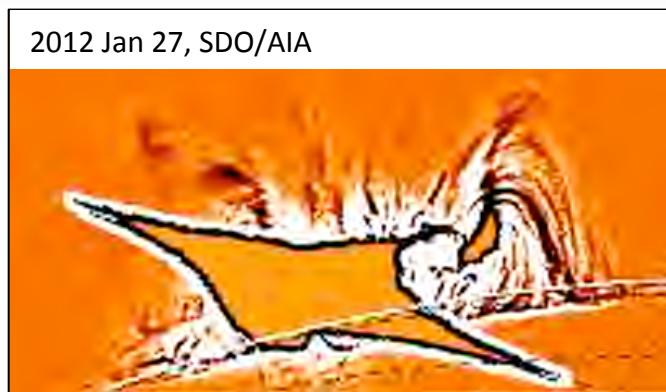
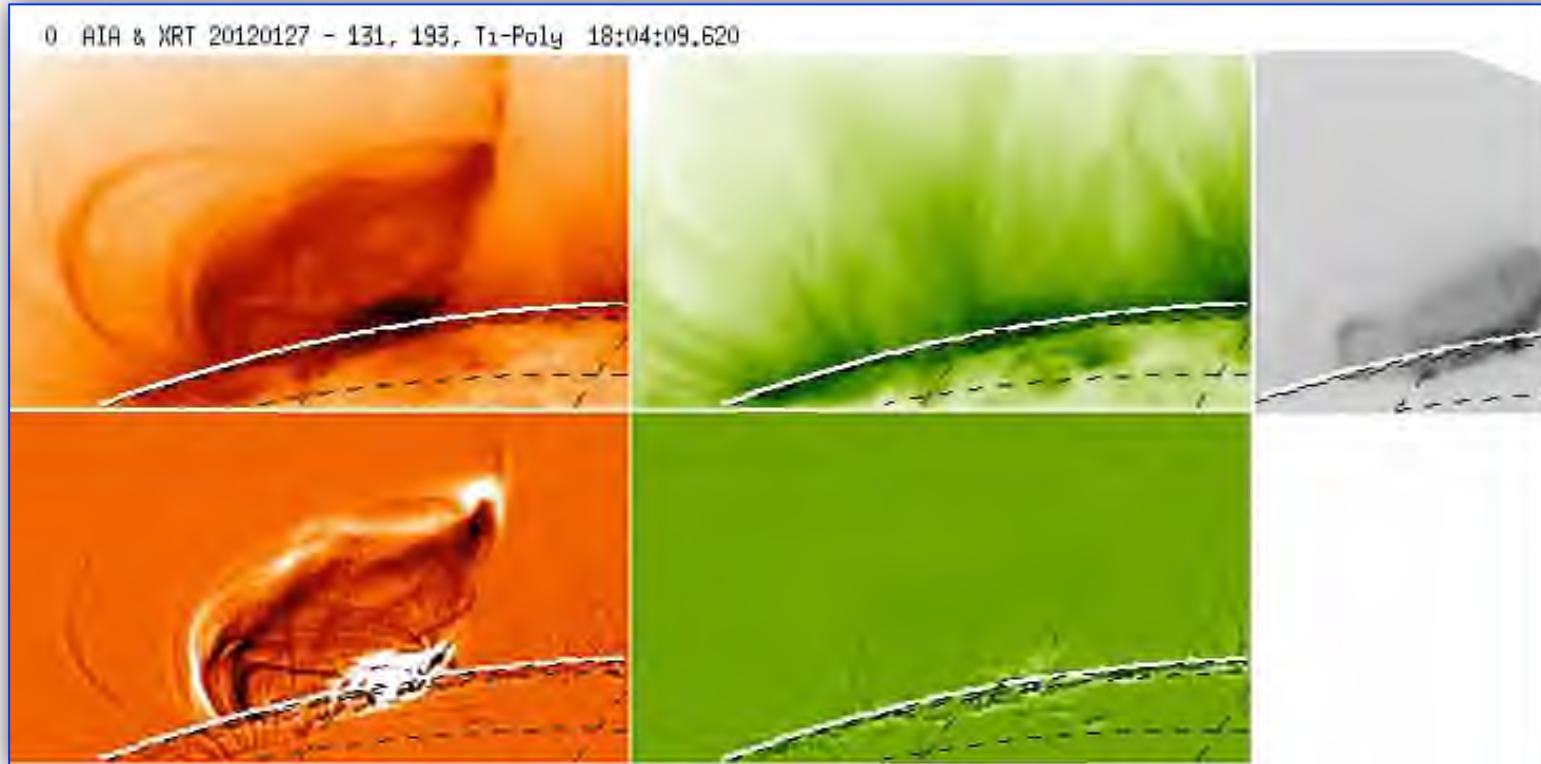


- SADs appear to be voids created by loops (SADLs) shrinking through the fan plasma.

Fig 2



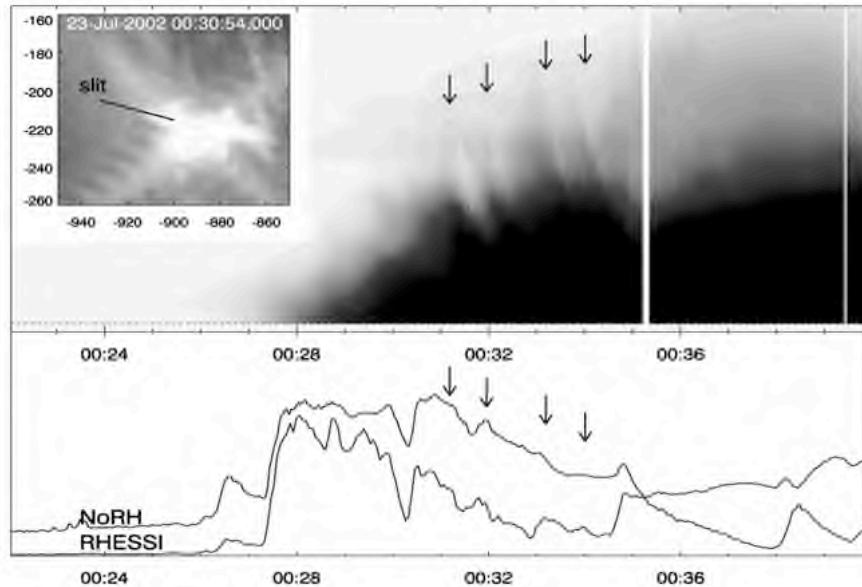
Supra-Arcade Downflowing Loops (SADLs) Observations



Particle Acceleration & Heating

RHESSI + TRACE

Fig 1



VLA + AIA + RHESSI

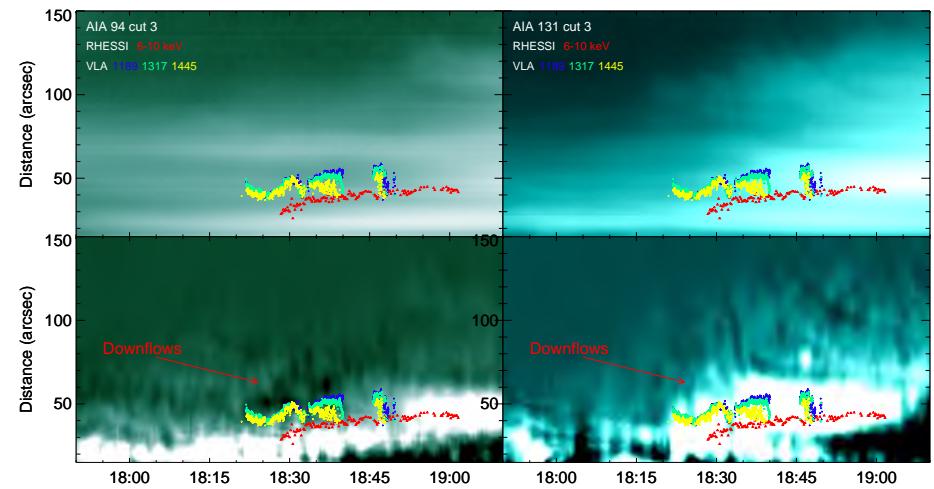
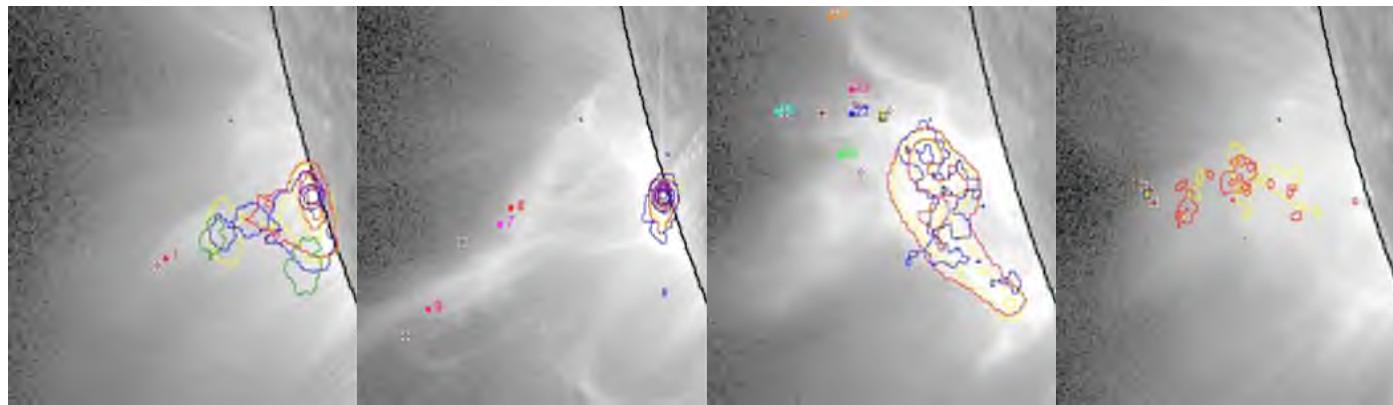


Fig 3

Fig 2



RHESSI + AIA

Savage – 2010 Nov 3 flare

Diagram Models

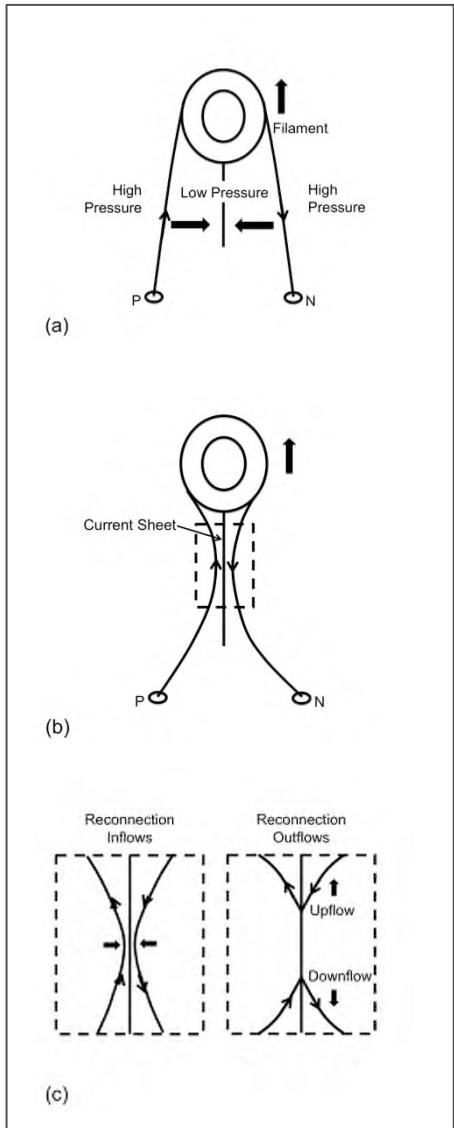


Fig 1

Fig 2

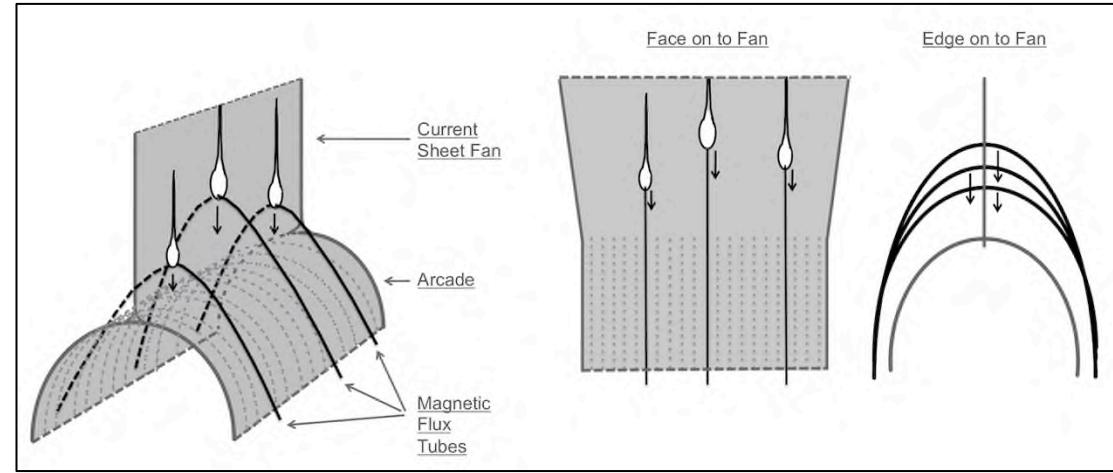
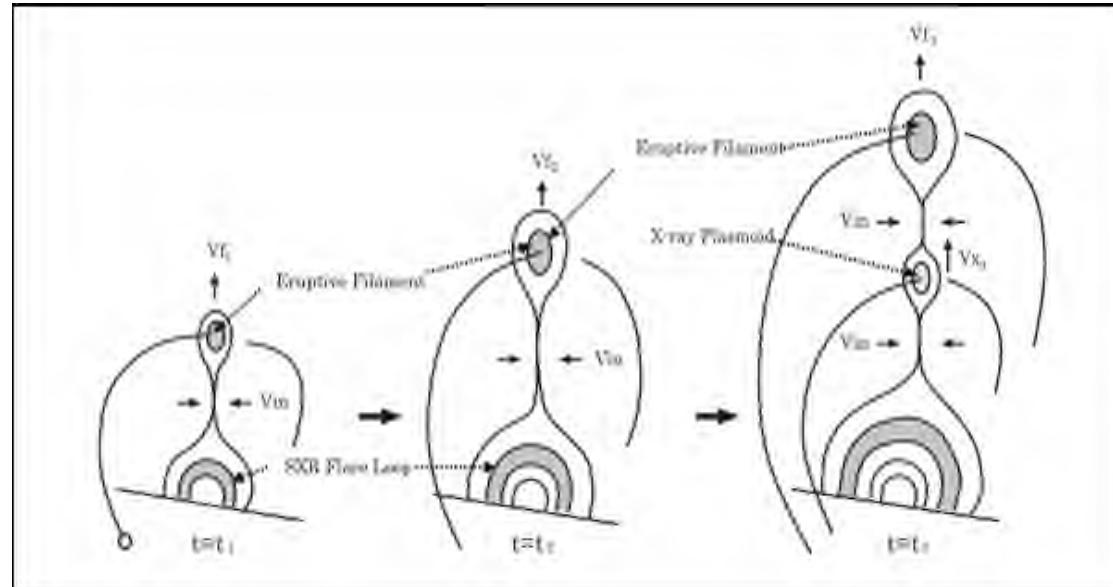


Fig 3



3D is Pivotal

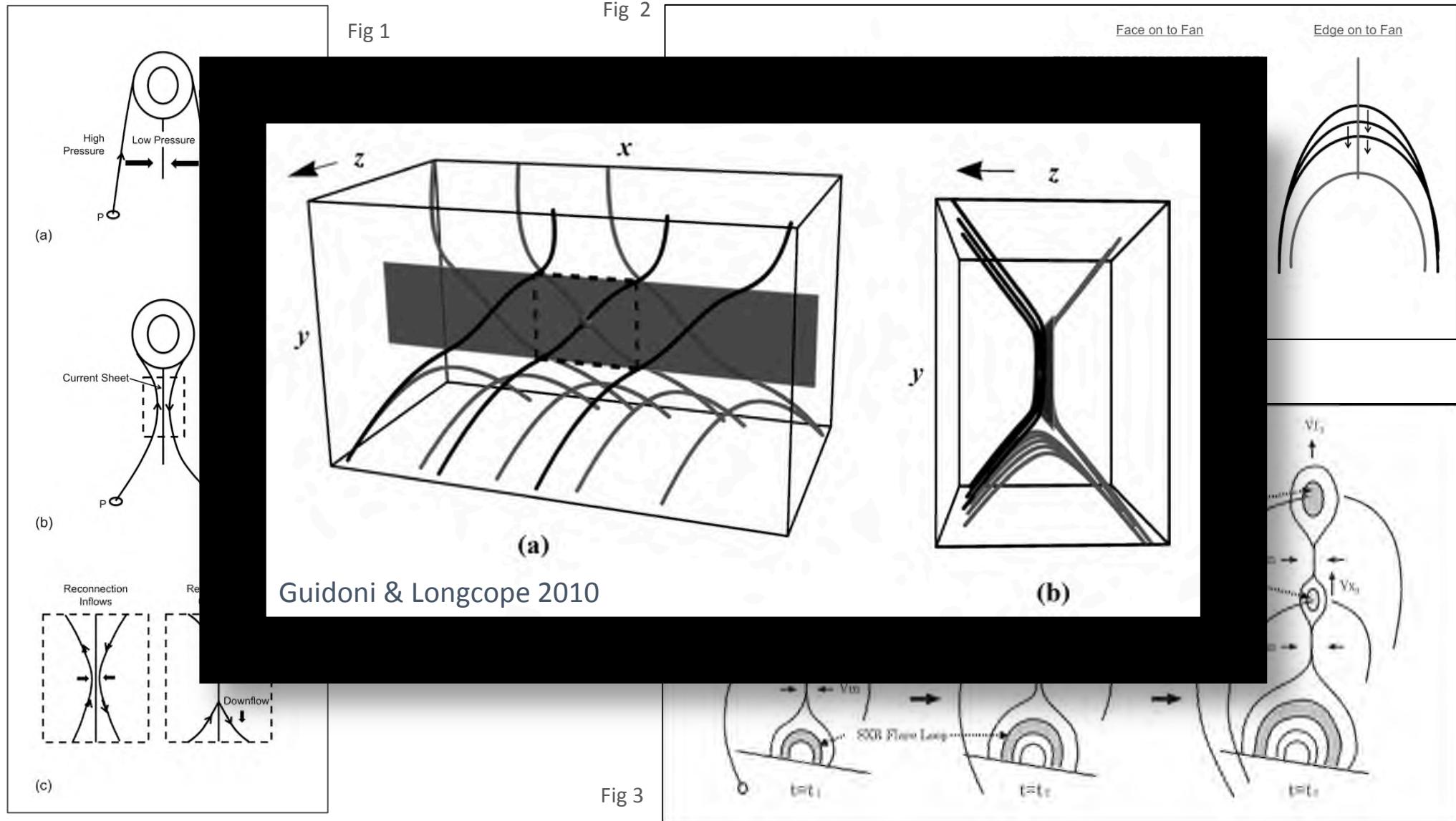
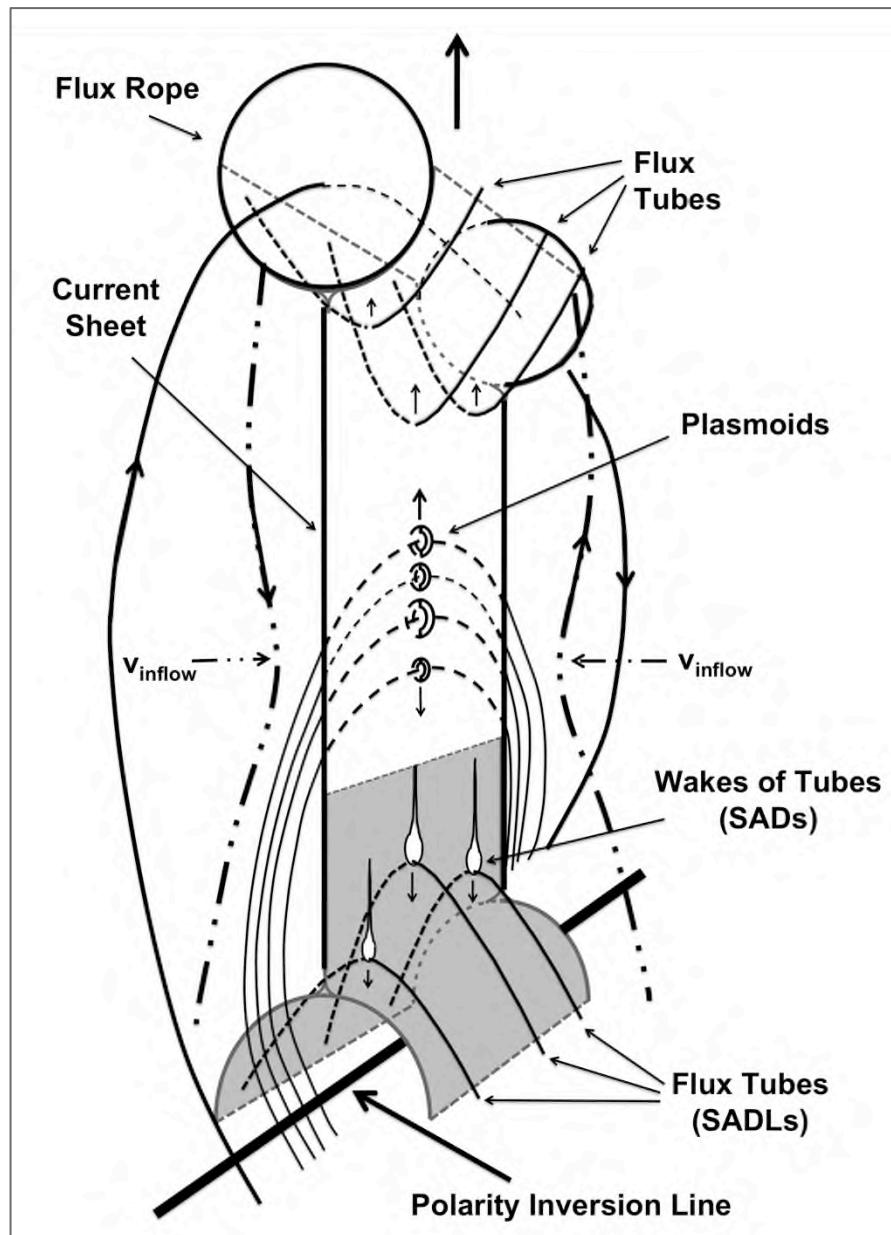


Fig 1



- Basic reconnection scenario, post initial flux rope formation and release.
- General organization of the magnetic field of the various components (SADs, SADLs, plasmoids).
- Field lines reconnect across the current sheet to form outflowing flux tubes while plasmoids form along the current sheet.
- SADs are formed as the flux tubes (SADLs) retract through hot plasma in the fan (*otherwise, only SADLs are observed*).

Strong potential analogy with magnetotail substorms

Fig 1

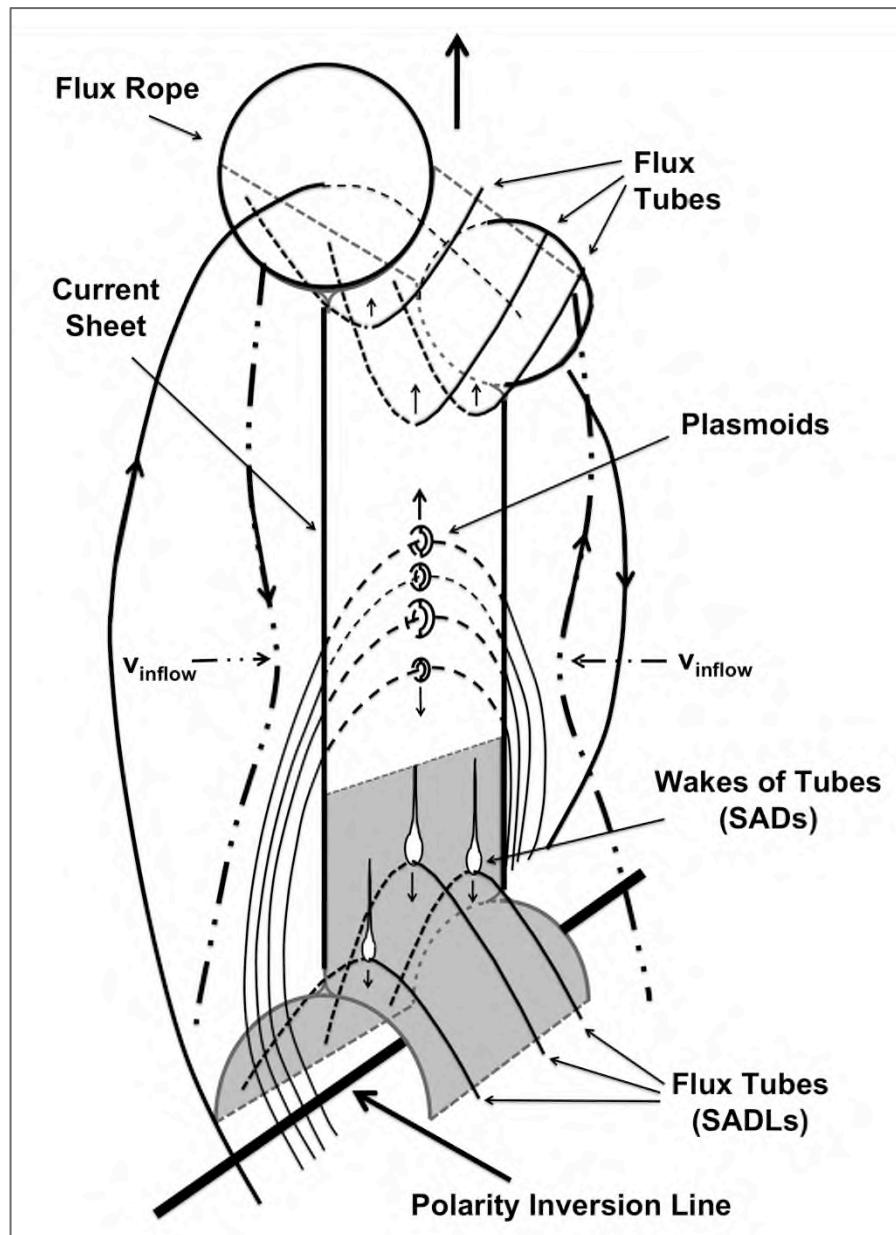


Fig 2

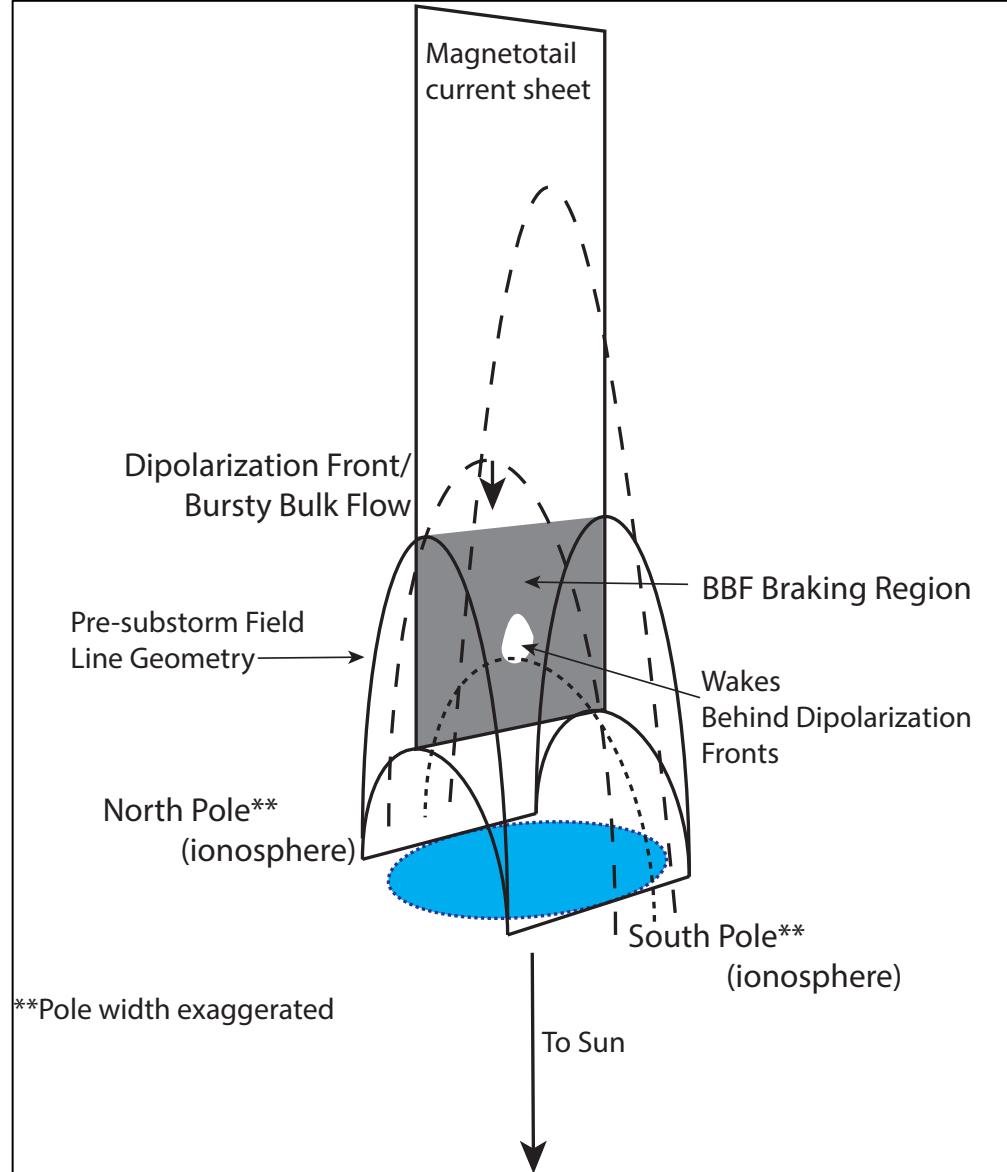


Fig 1: Savage et al. 2012

Fig 2: Courtesy of A. Kobelski, Reeves et al. 2008

Model Constraints

OBSERVED TEMPERATURE AND DENSITY ALWAYS LOWER THAN FAN

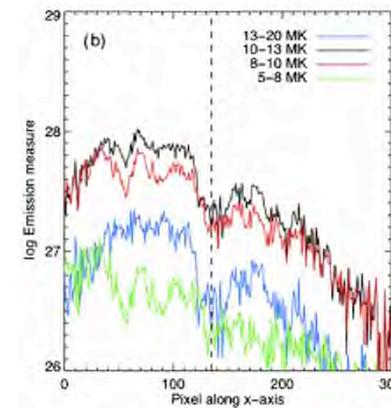
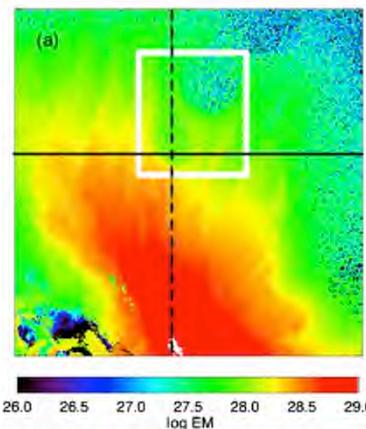


Fig 1

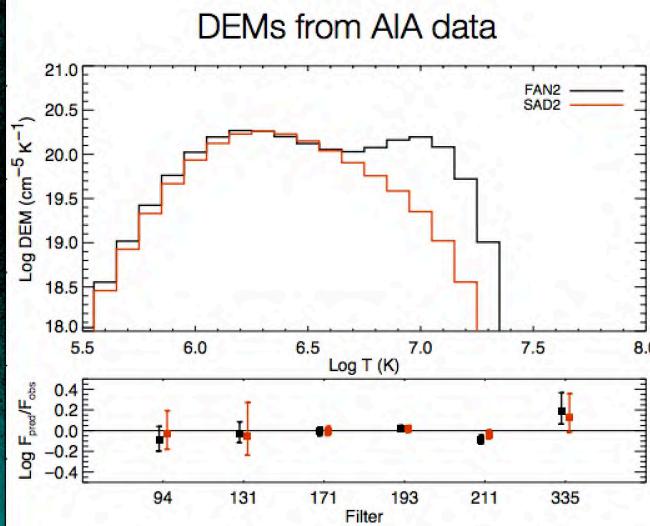
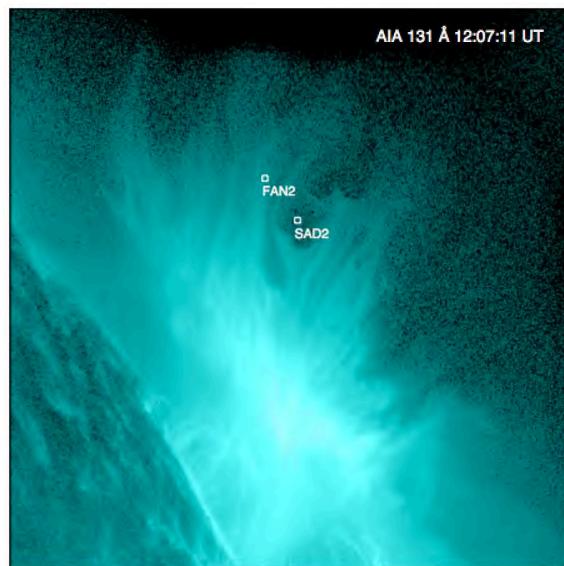
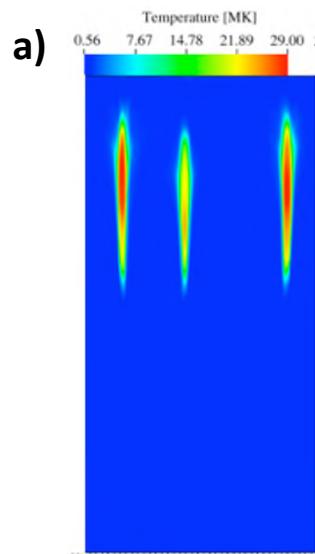


Fig 2

Model Simulations

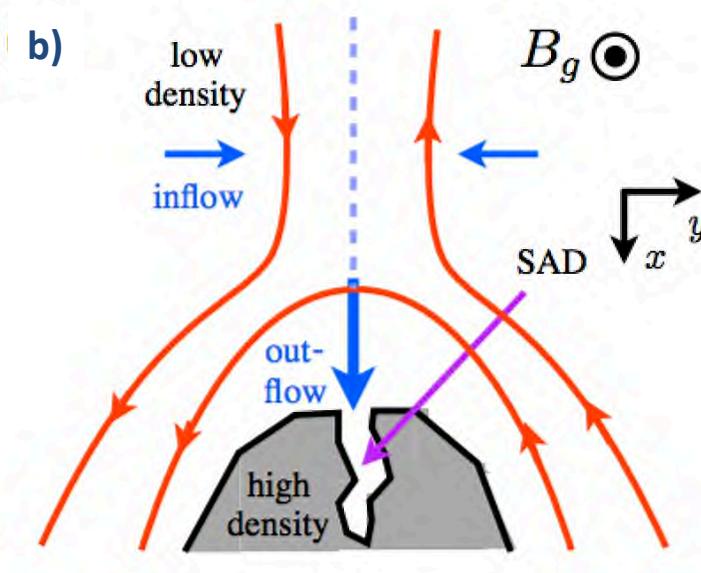


Pressure pulse + MHD wave

$(T \gg \text{fan})$



Too hot with respect to the surroundings

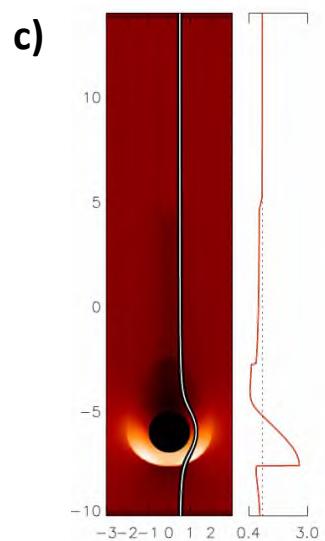


Reconnection outflows

$(T \sim \text{fan})$



Incorrect geometry with respect to observations

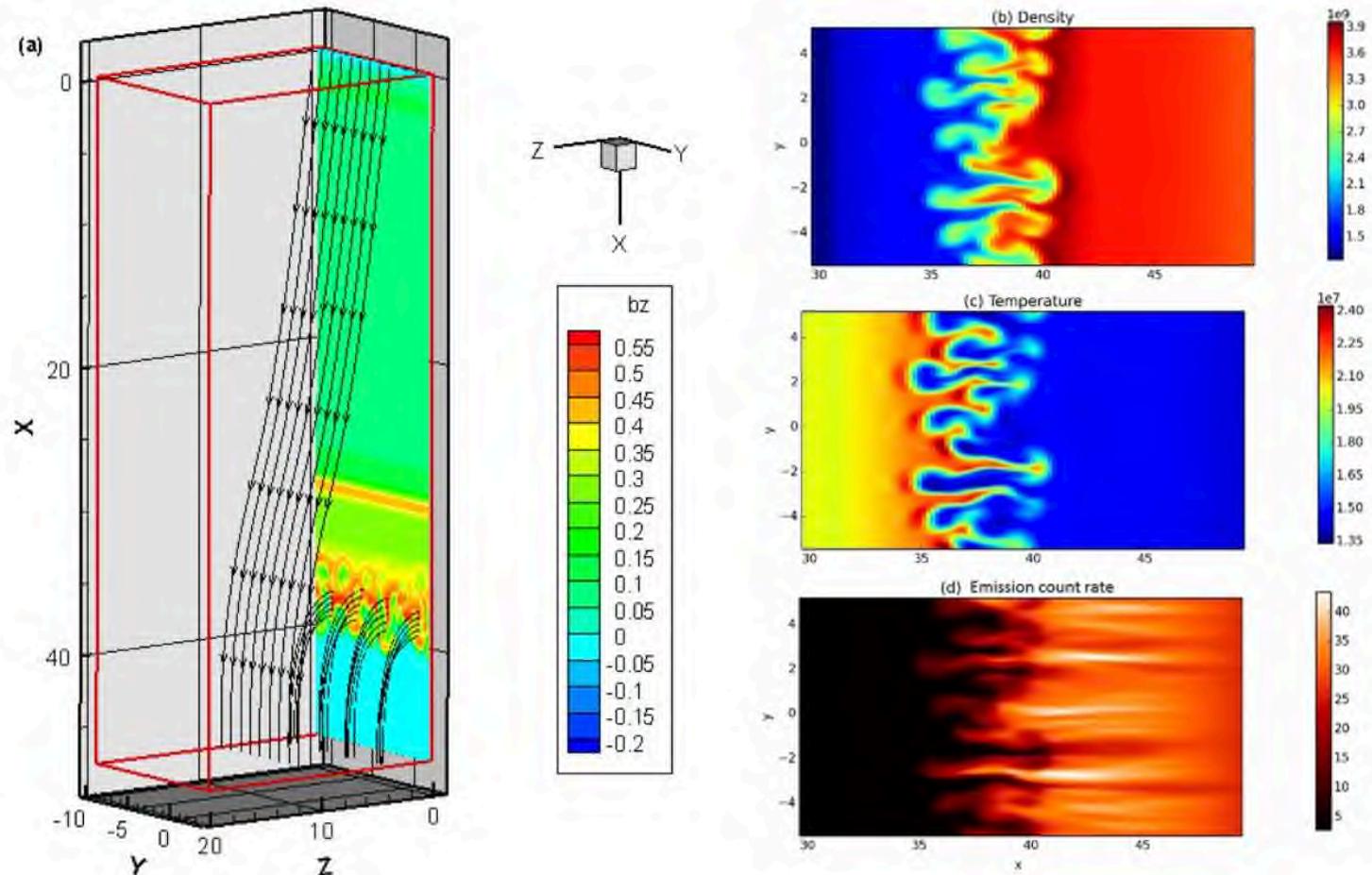


Peristaltic pumping

$(T \sim \text{fan})$

Incomplete, feasible;
Difficult to match to observations

Model Simulations



Rayleigh-Taylor Instabilities behind retracting flux tubes ($T > \text{fan}$)

Too hot with respect to the surroundings

BUT

Best match to observations to date (3D!!!)
although early in development

SADs in the Extended Corona

Fig 1

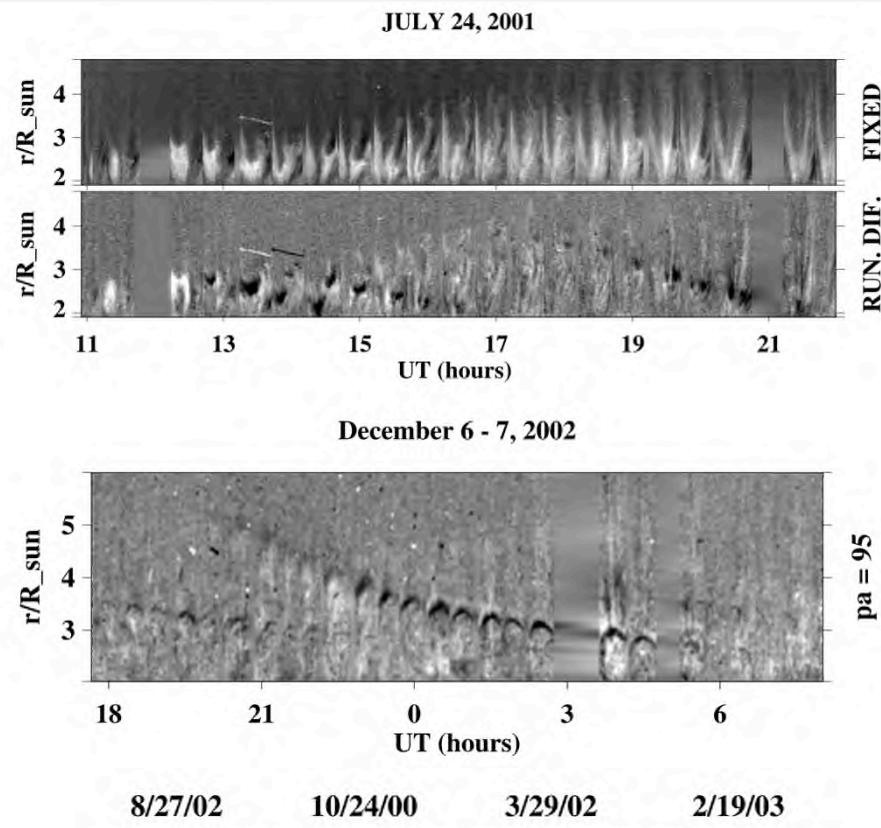


Fig 2

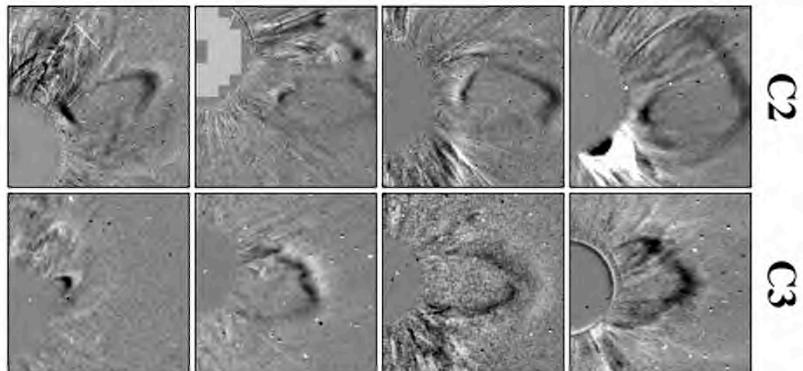
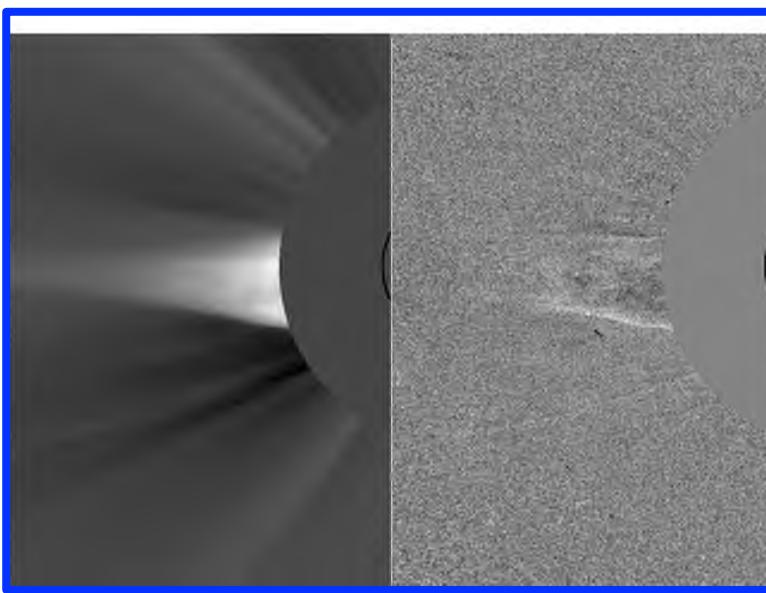
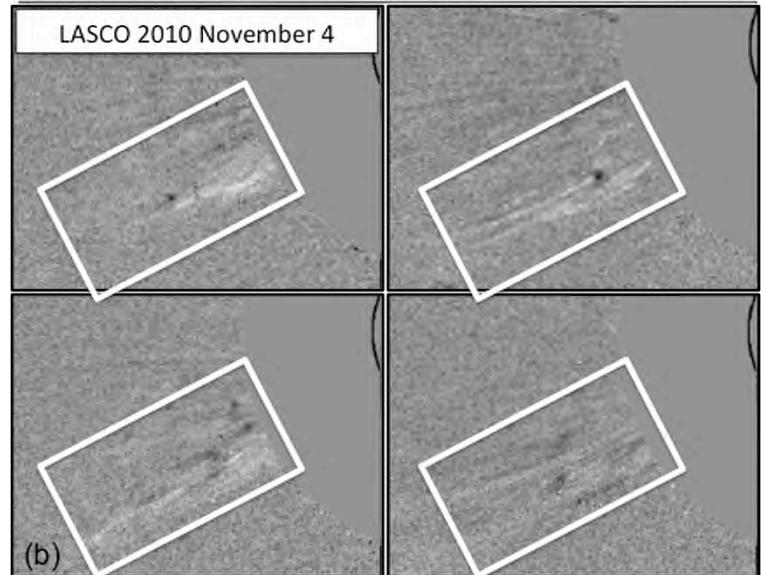


Fig 1: Sheeley, Warren, & Wang 2007

Fig 2: Sheeley & Wang 2007



SADs in the Extended Corona...

SADs in the lower corona are typically observed well after reconnection has occurred.

In the extended corona, we are better able to observe the migrating reconnection sites.

Coronagraphs allow us to see reconnection develop behind the CME while looking directly at the density.

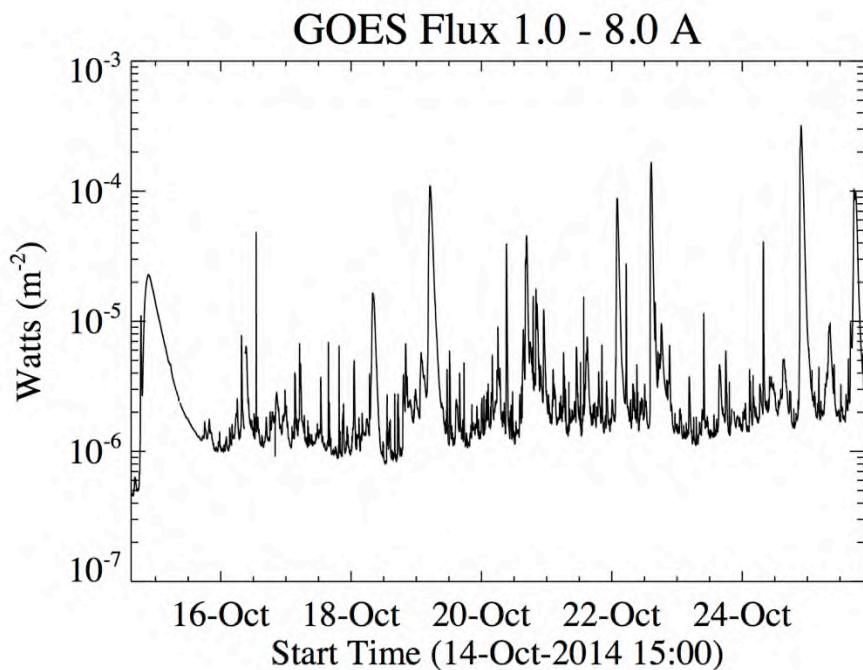
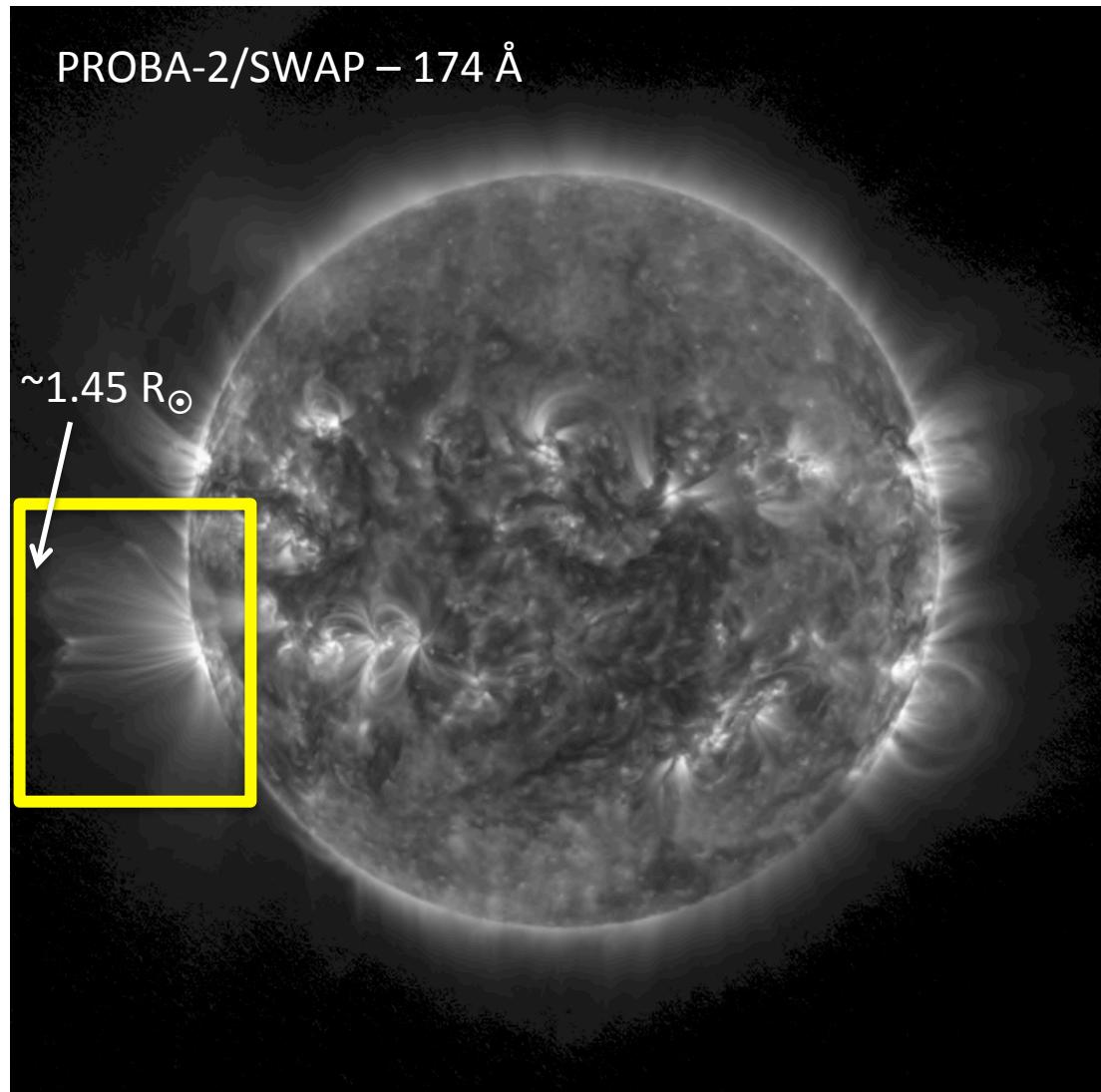


Fig 1

“Giant Arches” Flare – 2014 Oct 14



SADs in the Extended Corona...

LASCO C2
PROBA-2/SWAP
AIA 131 Å

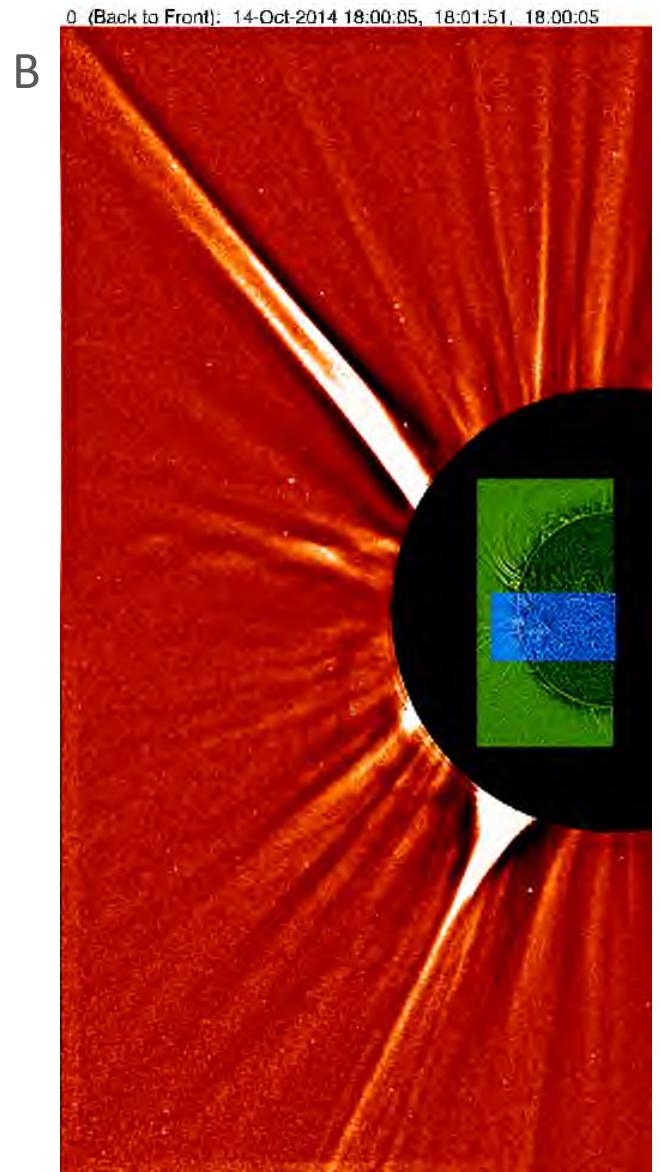
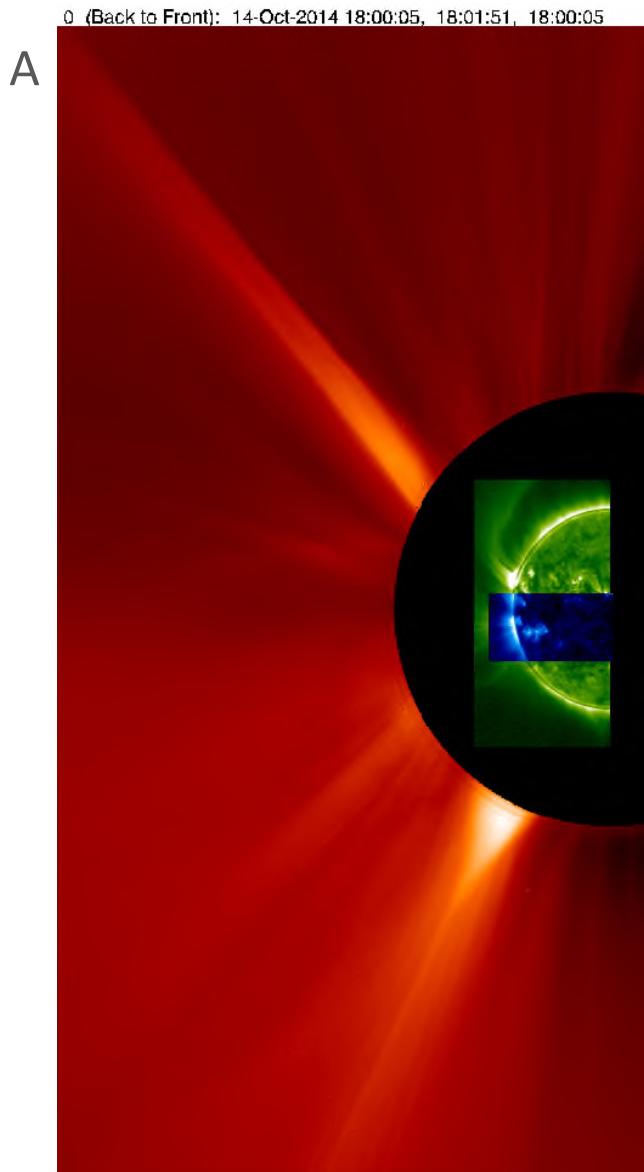
A: Flattened from a year's
worth of data

Cleaned (cosmic
rays, background
stars, planets)

Attenuated disk

B: Smooth-Differenced

- Scaled



SADs in the Extended Corona...

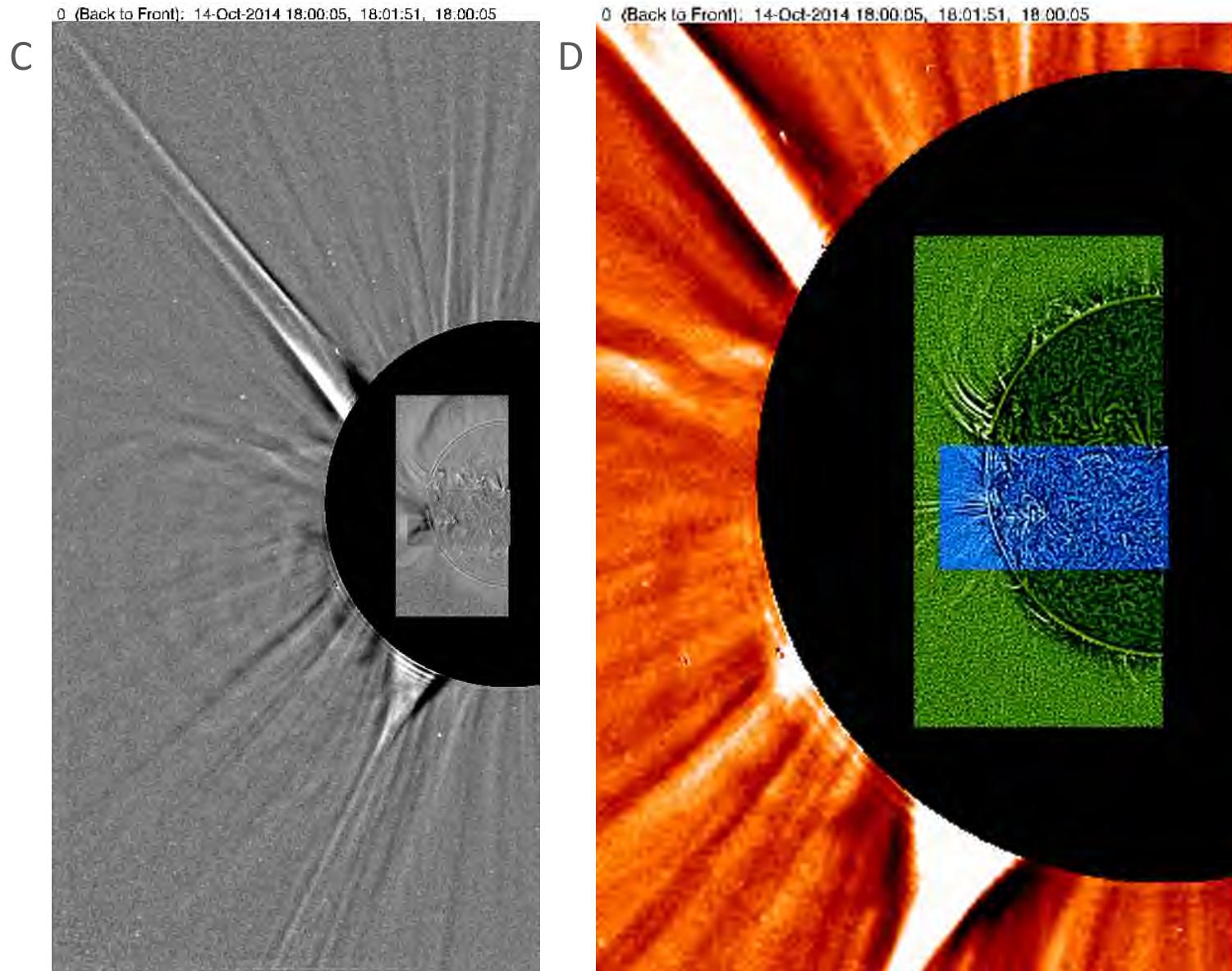
LASCO C2
PROBA-2/SWAP
AIA 131 Å

C: Run-Mean-Differenced

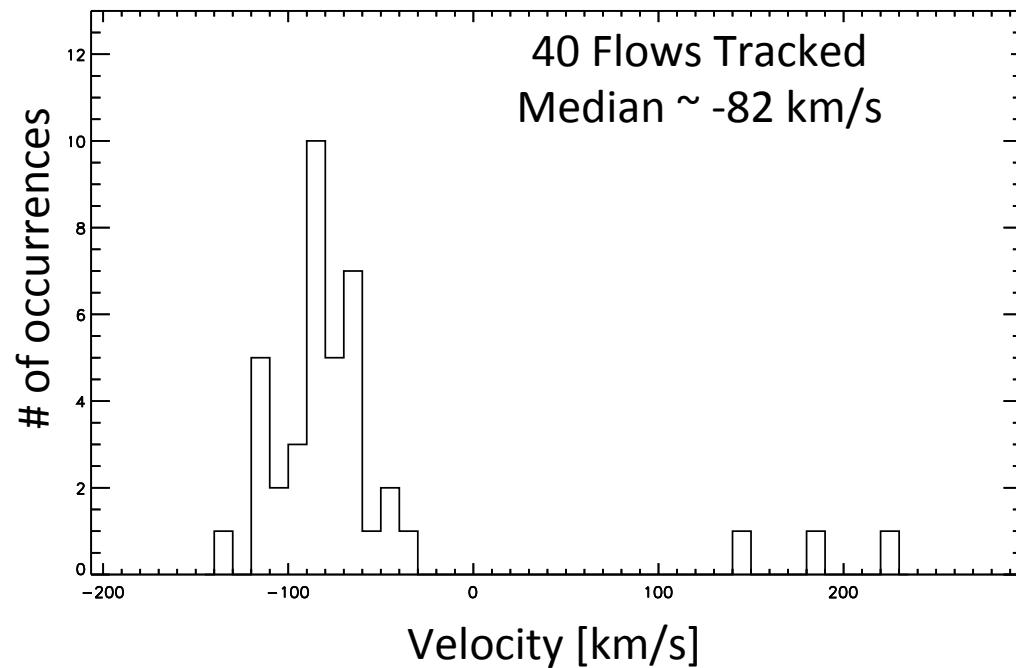
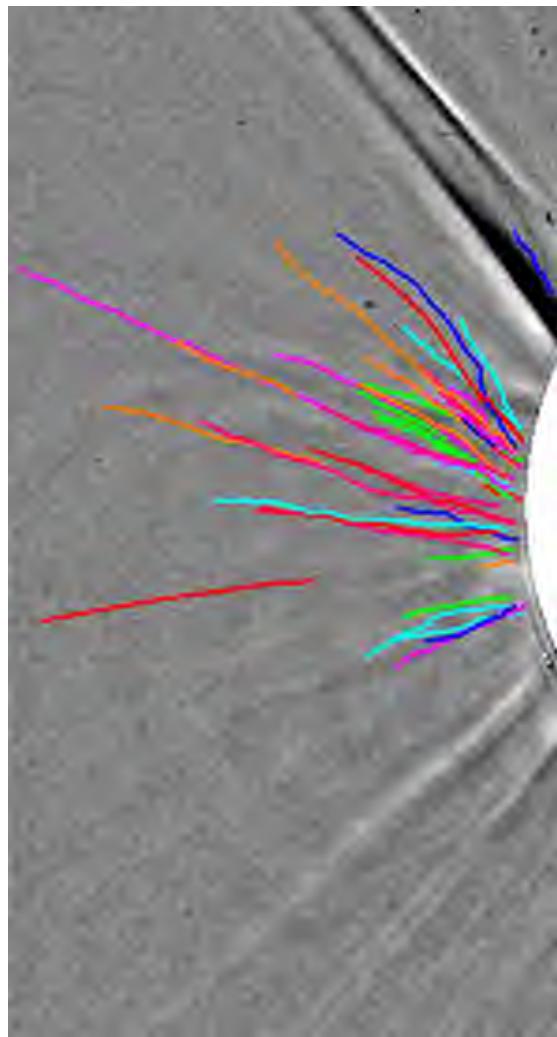
D: Smooth-Differenced

Extracted

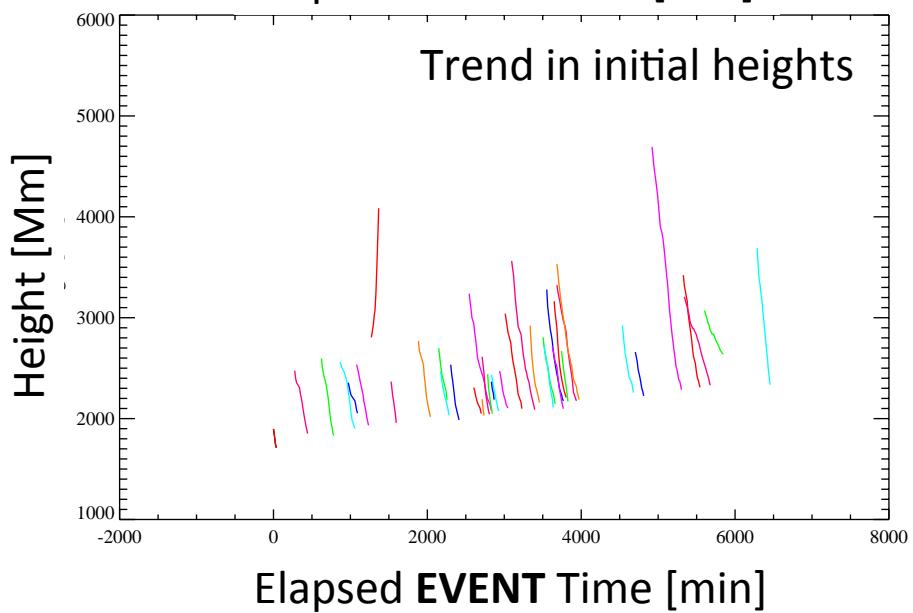
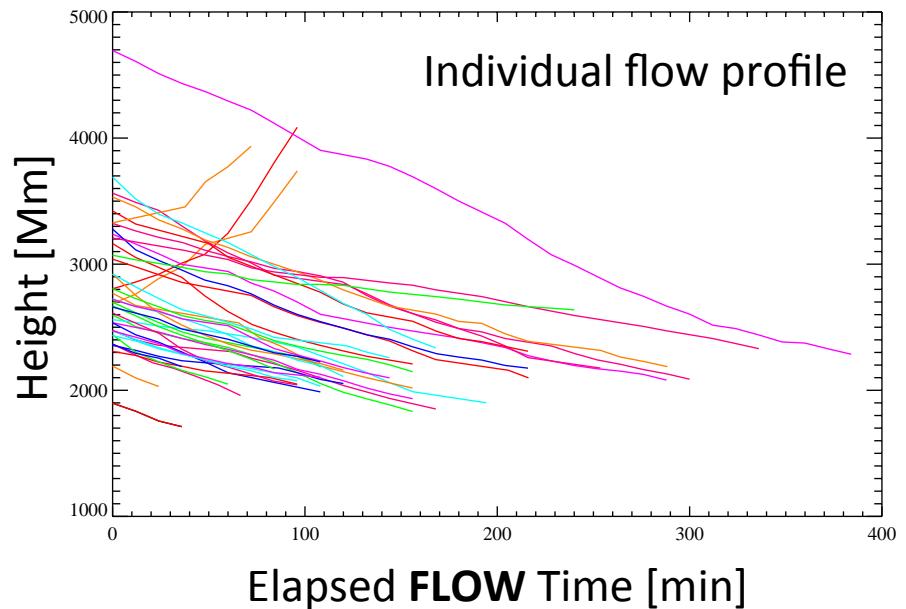
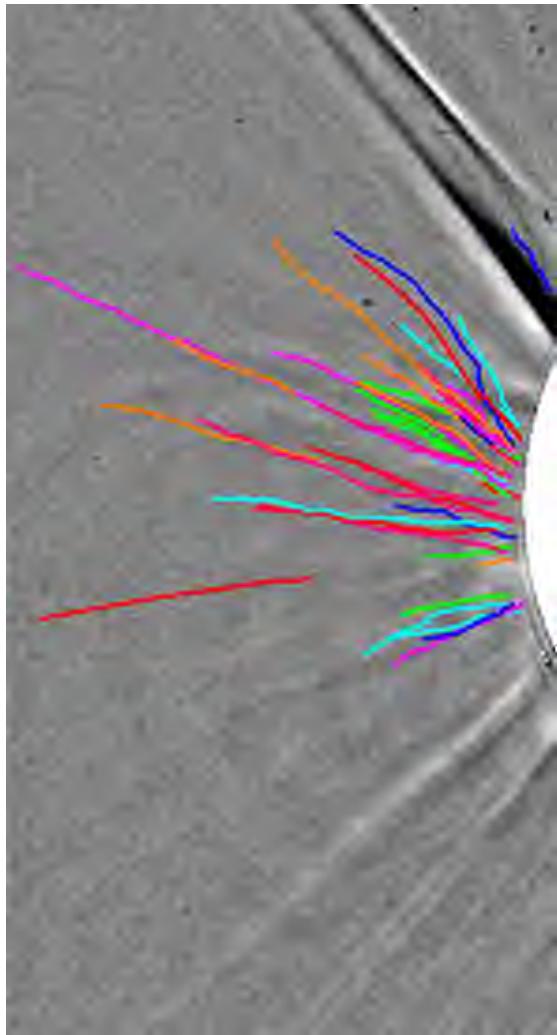
- Scaled



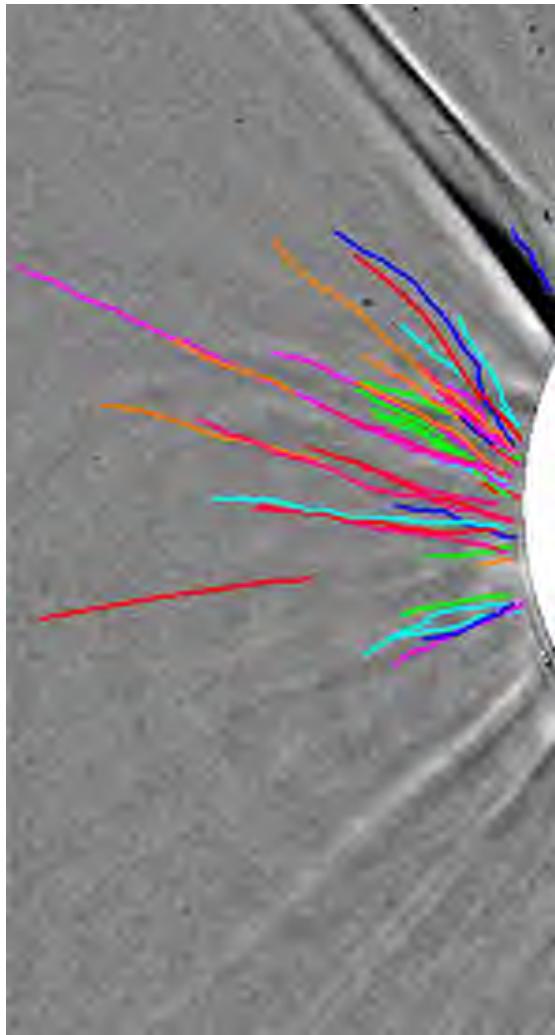
SADs in the Extended Corona...



SADs in the Extended Corona...

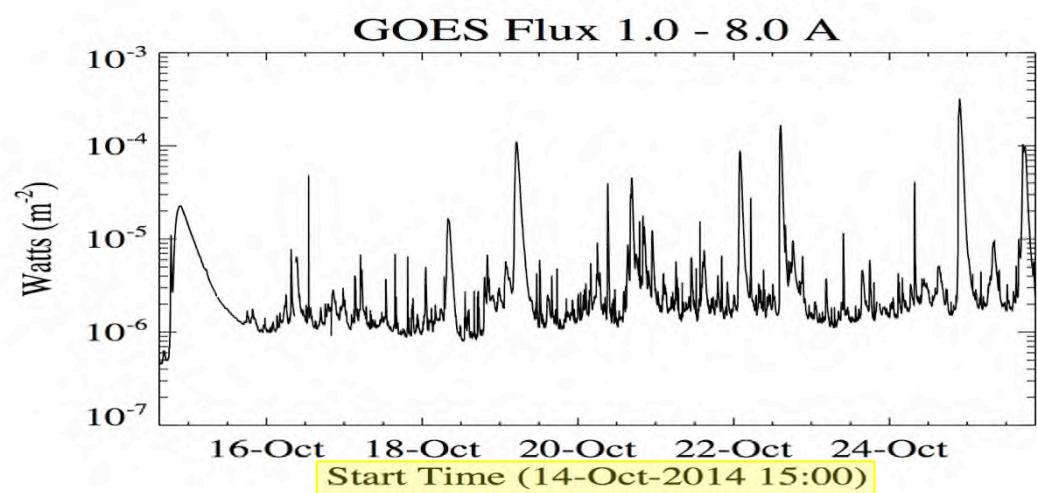
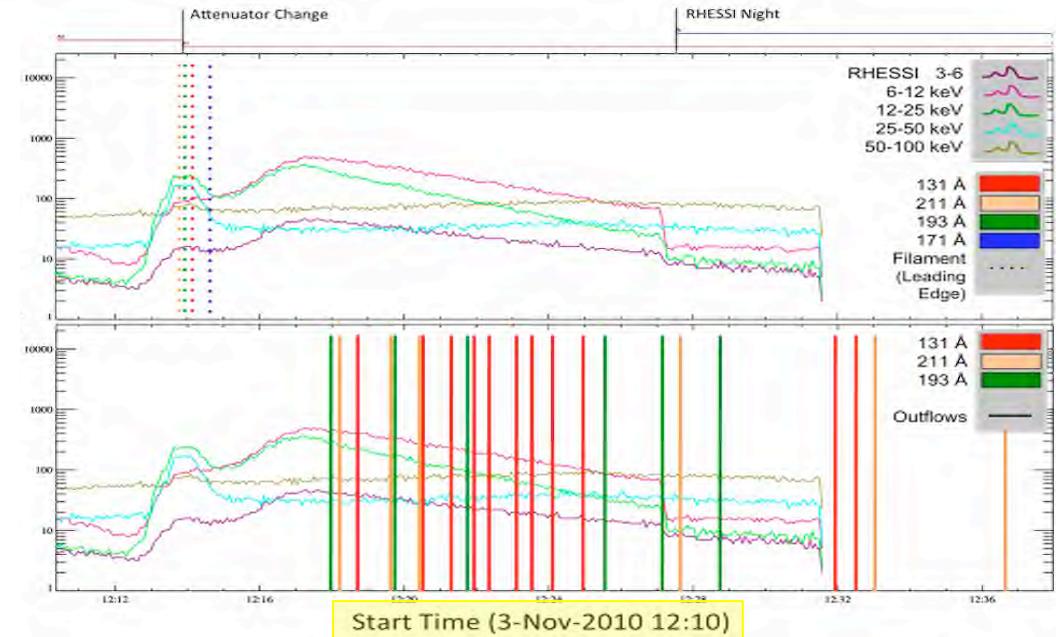


SADs in the Extended Corona...



TBD

1. Correlate flows directly to lightcurve as done for 2010 Nov 3rd event
2. Spatially and temporally correlate RHESSI and Hinode/XRT X-ray contours with outflows.





Summary & Forward Work

- Continuation of shrinking loops imparts energy into the current sheet long after the flare. Clearly.
 - But for an entire week??
 - Does this happen all of the time?
 - How did this one grow so large?
 - Density stratification? Active region interactions?
- Reconnection is fast and patchy.
- Add Hinode/XRT and RHESSI data (started).
- Do features track between fields of view both ways?
 - Initial work begun. (Some even in LASCO C3.)
- Need for instrumentation to fill the gap in observing the transition corona
 - Important to be in single wavelength
 - Possibly coming to an International Space Station near you....

